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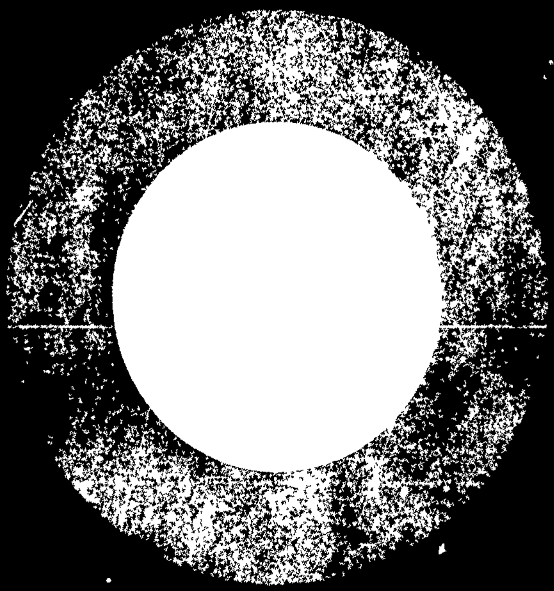
A study of total energy (central heating, cooling, lighting, and power systems) was made by an independent agency in order to objectively determine the implications and advisability for use in American schools and colleges. The resulting report includes case studies, feasability guidelines, plant and equipment design guidelines, and a discussion of future trends. This document previously announced as ED 018 959. (JT)

Total Energy



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Total Energy

A Technical Report from
Educational Facilities Laboratories

"... follow the track of the energy;
to find where it came from and
where it went to; its complex source
and shifting channels; its values,
equivalents, conversions."
Henry Adams, *The Education of Henry Adams*

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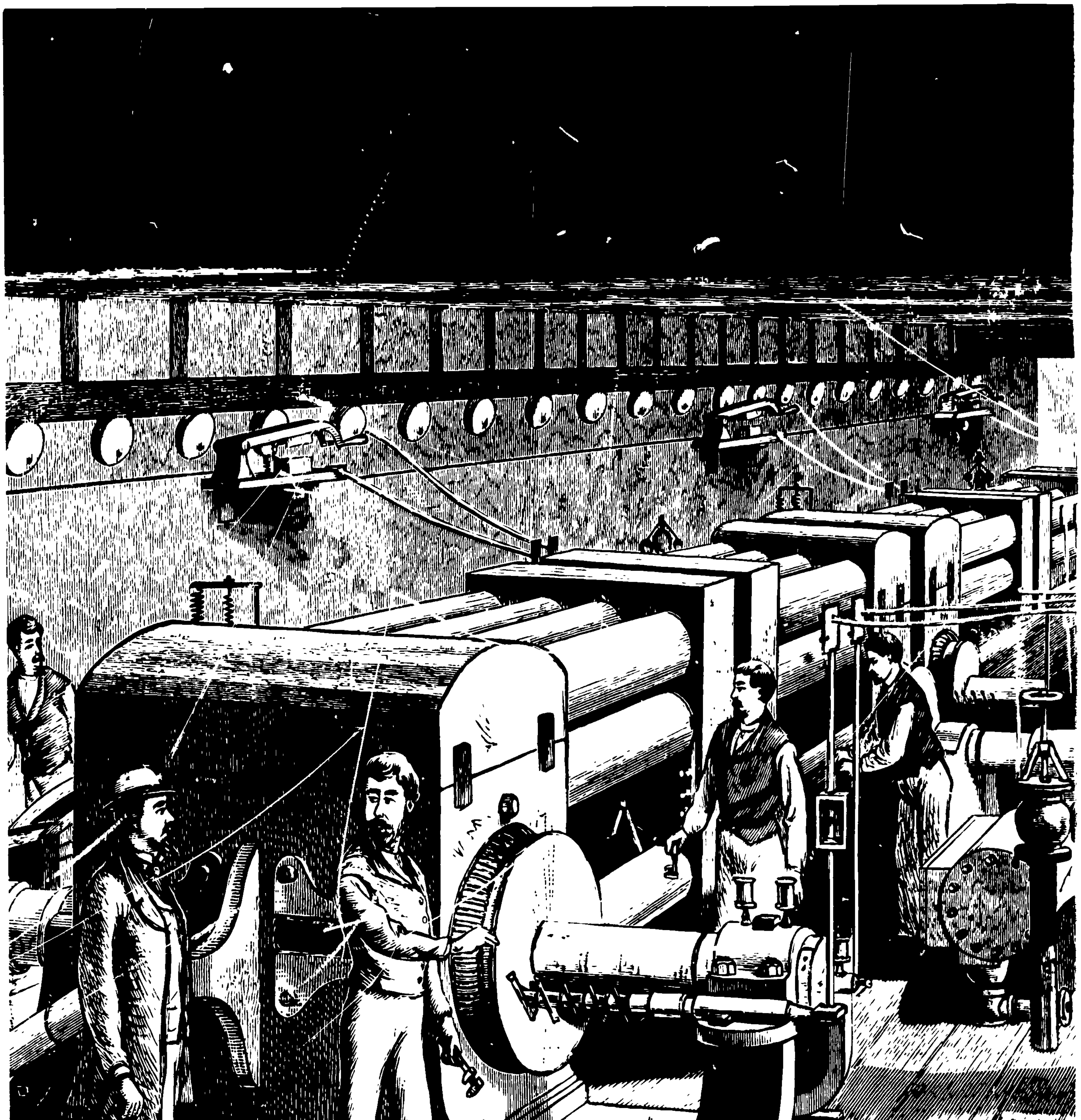
This report is based on a research project conducted for Educational Facilities Laboratories by Fred S. Dubin Associates, Consulting Engineers. Norman Kurtz, P.E. was research director for the project and prepared the original report. Special segments were written by Anne Le Crenier. The report was edited by Gaila P. Coughlin and Ronald W. Haase, A.I.A.

We would like to acknowledge the help of William Ericksen of the George A. Fuller Construction Company and John E. Plantinga of Meyer, Strong & Jones, Consulting Engineers, for reading the manuscript and for their useful suggestions regarding it.

In preparing this report, two groups of readers were considered: one, educational administrators and business managers interested in new trends and developments in school and college design, and two, architects and engineering consultants concerned with the technical and economic implications of these new developments. The Introduction and Case Studies are directed toward the entire audience. The chapters on Feasibility and Design were written largely for the second group.



Foreword

This report deals with a new approach to on-site power generation providing school buildings with heating in winter and cooling in summer as well as light and power all year round. This approach, with its adman's tag of "total energy," has many advocates, disciples, and hucksters. Since this new concept enters into direct competition with traditional purveyors of electric power —the local utility companies—it has as well many opponents. The climate seemed ripe for a disinterested third party to step in: hence EFL's interest and this report.

EFL's goal in supporting this study of total energy was to determine objectively its implications and advisability for American schools and colleges. Considering the increased proportion of school building dollars going into mechanical and electrical engineering features, this alone would be justification for our concern.* In addition, the notion of a school building as something to be operated on a 9 to 3 schedule, 5 days a week, 9½ months a year is rapidly going the way of the little red schoolhouse itself. Consider these straws in the educational wind:

Classrooms and shops in a Clark County, Nevada, vocational center are being planned for 24-hour-a-day operation.

California's entire system of state colleges is undergoing a transition to a year-round schedule. By 1975 the state colleges will be offering courses on a full-year, four-quarter schedule.

In Dade County, Florida, last summer, 157 of the district's 204 schools had some form of enrichment or remedial program in operation.

Cities across the nation held classes for over 500,000 underprivileged preschool children as "Project Head Start" got under way during the summer of 1965.

These changing demands have placed new responsibilities on school and college planners. Today, for example, air conditioning is less of a luxury than a necessity in buildings that are used 12 months a year. Even in northern states, engineers have long been aware that simple ventilation with outside air is not enough to keep students alert or to comfort a heat rash when outside air temperatures rise above 60 degrees Fahrenheit.

Evening classes, multifunction buildings, year-round air conditioning, the increased use of electronic teaching aids all add up to one indispensable fact: the energy requirements—for light and power, heating and cooling—of the modern educational institution are as different from those of the pre-1950 school as a programed teaching machine is from a McGuffey reader. With this in mind, each new proposal for an economical approach to providing our schools and colleges with the best environment for learning is worth examination.

Dealing with both initial *and* operating costs of mechanical and electrical systems, this report presents design alternatives measured on the basis of *long-range* engineering economics. For many school districts and college administrators this may represent a departure from attitudes toward building expenditures judged solely on a first-cost basis. The difference is significant and reflects an exacting concern with how the taxpayer's (or contributor's) dollar is spent. The report examines and advocates higher initial investments when balanced by greater long-range operating economies. If it can in some measure influence administrations to consider public educational expenditures as private business considers capital investments for plant, its major purpose will have been served.

Educational Facilities Laboratories

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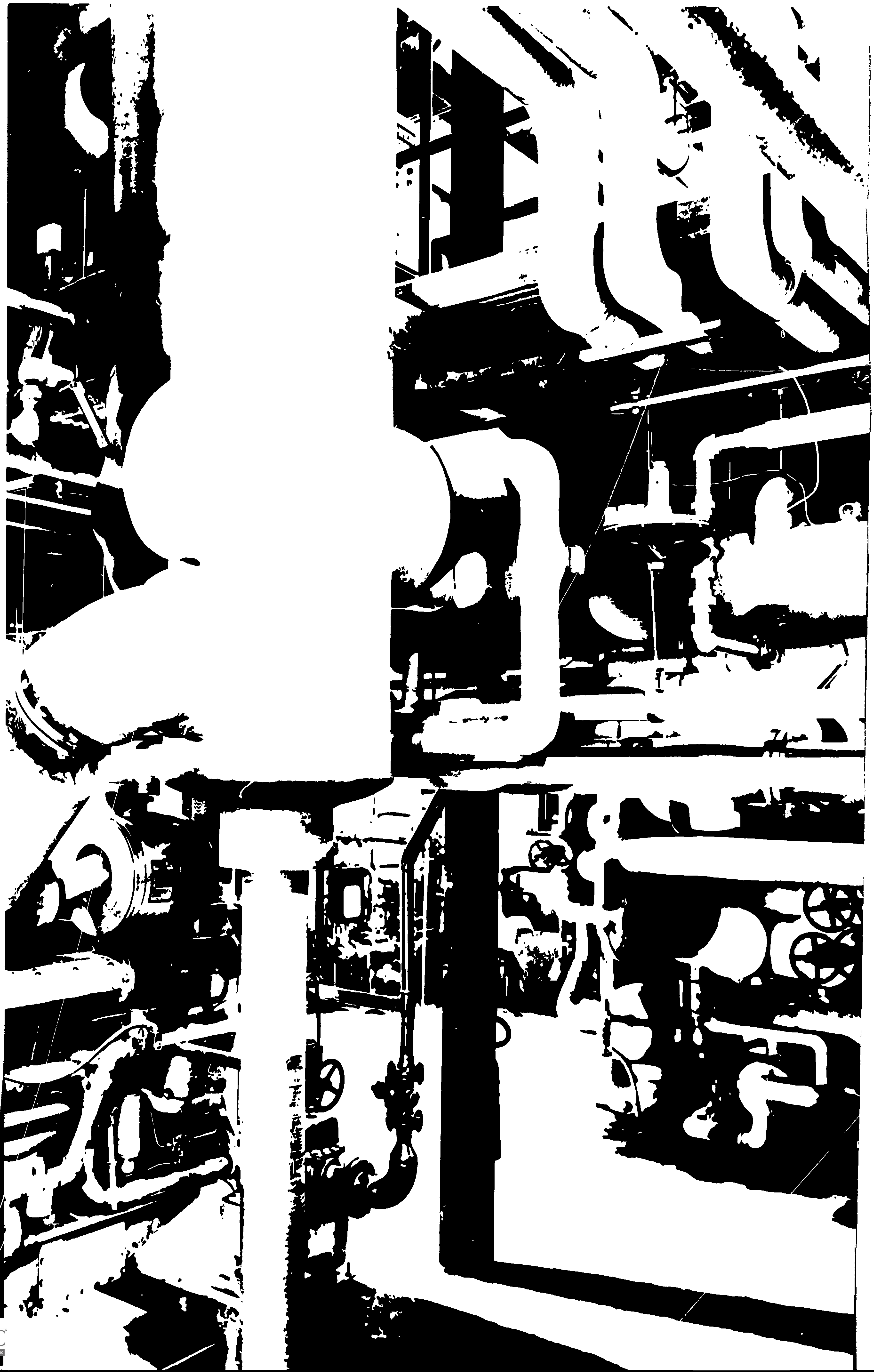
*An EFL survey made in conjunction with this report underscores the upward trend in mechanical and electrical costs. In Florida, Texas, and Nevada, where total climate control is gaining acceptance, the mechanical portions of school contracts have increased 5 to 10 per cent in the period between 1955 and 1965. Even as far north as Chicago, where the Windy City boasts one lone air-conditioned school, mechanical contracts have increased from 28 per cent to 33 per cent in that 10-year period.



1. Introduction to Total Energy

The summer of 1964 found 100 residents of West Jasper Place, Alberta, Canada, attending sessions in industrial arts in the new Hillcrest Junior High School. Anticipating just such seasonal use, the West Jasper Place Board of Education had agreed that air conditioning was an essential in their compact school, and had included the additional funds needed in the school's construction budget. So far, nothing unusual; thousands of new schools are being planned and built with central air conditioning. What makes the Hillcrest school a pacesetter is that its air-conditioning system, according to current estimates, will have paid for itself in less than five years. What's more, after this unusually short write-off period, the Hillcrest school will get a substantial portion of its classroom cooling essentially "for free."

How did West Jasper Place, Canada, pull off this latter-day miracle? The key in this case—and possibly in many future cases—is the catchy term *total energy*.

The idea of total energy is deceptively simple; its ramifications are fascinating. The school or college installs its own electric generating system, then captures the system's "waste heat," converts it into steam or hot water, and uses this by-product for heating, air conditioning, and domestic hot water. In appropriate situations, fuel costs to power the generating system are less than the cost of electricity from a public utility. And the heat supplied by the recovery system represents fuel that would otherwise have to be paid for.

The idea is more than a dream on an engineer's drawing board. Since 1960, such self-contained systems have been supplying the total energy needs of 205 shopping centers, industrial plants, and commercial buildings. Reports have shown significant savings in operating costs all the way from City of Industry, California (Trend Mills: "a generating plant profit of $13,000 per year"), to Chelmsford, Massachusetts (J. M. Fields Quality Discount Store: "expect to save $23,650 annually") The success of these business ventures has been reflected in the installation of total energy systems in a number of schools, with results that are very encouraging.

Clearly, the total energy concept is something to be explored by a Board of Education or College Building Committee looking for ways to effect substantial economies in their future building programs. Just as clearly, a total energy system requires a careful investigation of the factors involved in each individual situation. It presents a new set of technological problems to engineers. It demands painstaking assembly and analysis of economic data and engineering figures. It involves the question of school-plant economics in both the short and long range.

In sum, a knowledge of what total energy is, its value, and its pitfalls, is needed in order to be able to make a reasoned judgment as to the feasibility of this system in a given situation.

On-Site Power Generation Comes Full Circle

The idea of generating electricity from a privately owned power source is not new. At the 1899 convention of the American Institute of Architects, engineer E. R. Hill delivered a paper on "Electricity in Modern Buildings," in which he exhorted the architects to take cognizance of the application of electricity.

His dissertation was directed to an appropriate audience. In those days there was nothing at all unusual in designing buildings with self-contained electric power generation. Many structures, including such notable examples as New York's Park Row Building, Chicago's Board of Trade Building, and even the U.S. Capitol in Washington, generated their own electricity for elevators, ventilators, call bells, and fire alarms—as well as for arc and incandescent lighting.

Many of the homes of the very rich had their own private electric plants. George J. Gould's estate in Lakewood, New Jersey, boasted direct-current, engine-type dynamos driven by two gasoline engines. Electricity from this system lighted his house and grounds, operated a refrigerating plant, ran a laundry, and even powered electric cigar lighters and his wife's hair curler.

In the heart of New York City, the Vanderbilt Mansion was powered, for a time, by its own Edison-designed generating plant until Madam, distressed by its noise, made the Commodore remove it from the premises forthwith.

A new trend was growing, however. In 1882, Thomas Edison's Pearl Street Station had begun providing electricity to shops and homes in the one-square-mile area called "First District of New York." Although destroyed by fire in 1890, the success of this first central power station led to the building of others in city after city. By the early 1900's, private on-site power generation was being rapidly replaced by the purchase of power from one central source. Since then, purchased power has been the norm, until recent developments have again raised the question of its advisability.

Waste Not, Want Not: How a Total Energy System Works

If on-site power is nothing really new, the idea of reclaiming its waste-heat by-product and using it to power other building services certainly is. In recent years, the science of heat recovery has reached new levels of efficiency, thanks to lessons learned in nuclear power application, rocketry, aviation, and similar space-age developments. Today there is renewed interest in building complexes which, like medieval castles, are self-sufficient, and in which the single most economical energy source—whether it be gas, oil, or even coal—can be utilized to operate a completely integrated system of mechanical services.

A typical total energy system consists of several carefully combined components. An electric generator is powered either by a turbine or a reciprocating engine. A recovery system reclaims the heat produced by the turbine or the engine, in the form of either steam or hot water. The recovered steam or hot water is then used for heating or, through the use of absorption-type refrigeration units, for cooling. (A description of absorption cooling is given in Appendix A.)

The turbine and the reciprocating engine handle heat recovery differently. In the case of the turbine, exhaust gases pass through waste heat boilers which convert the energy into steam or hot water. In the reciprocating engine system, both the engine's jacket cooling water and the hot exhaust gases are passed through heat-exchangers to obtain hot water or steam.

The lure of the total energy concept lies in this recovered heat. It is in a sense free energy, since its equivalent would have to be replaced by purchase from outside sources in the form of other fuels or electricity.

Where Total Energy Schools Exist, How Successful Have They Actually Been?

At the time of this writing, nine schools employing total energy concepts are already in operation, with an additional half dozen either on the drawing boards or nearing completion. Two of those under construction are colleges: Oral Roberts University in Tulsa, Oklahoma, an entirely new campus using gas-fired turbines as prime movers; and Lewis College in Lockport, Illinois, where a new gas-engine central power plant will serve the expanding campus. Of the nine schools which have been in operation for more than a year, all claim considerable savings in annual operating costs over purchased power alternatives. Case histories of two are presented here in detail to illustrate possible choices of components and present sample cost data. A listing of all installations and a brief description of their total energy plants may be found on page 17.

Figure 1. Total energy system using turbine

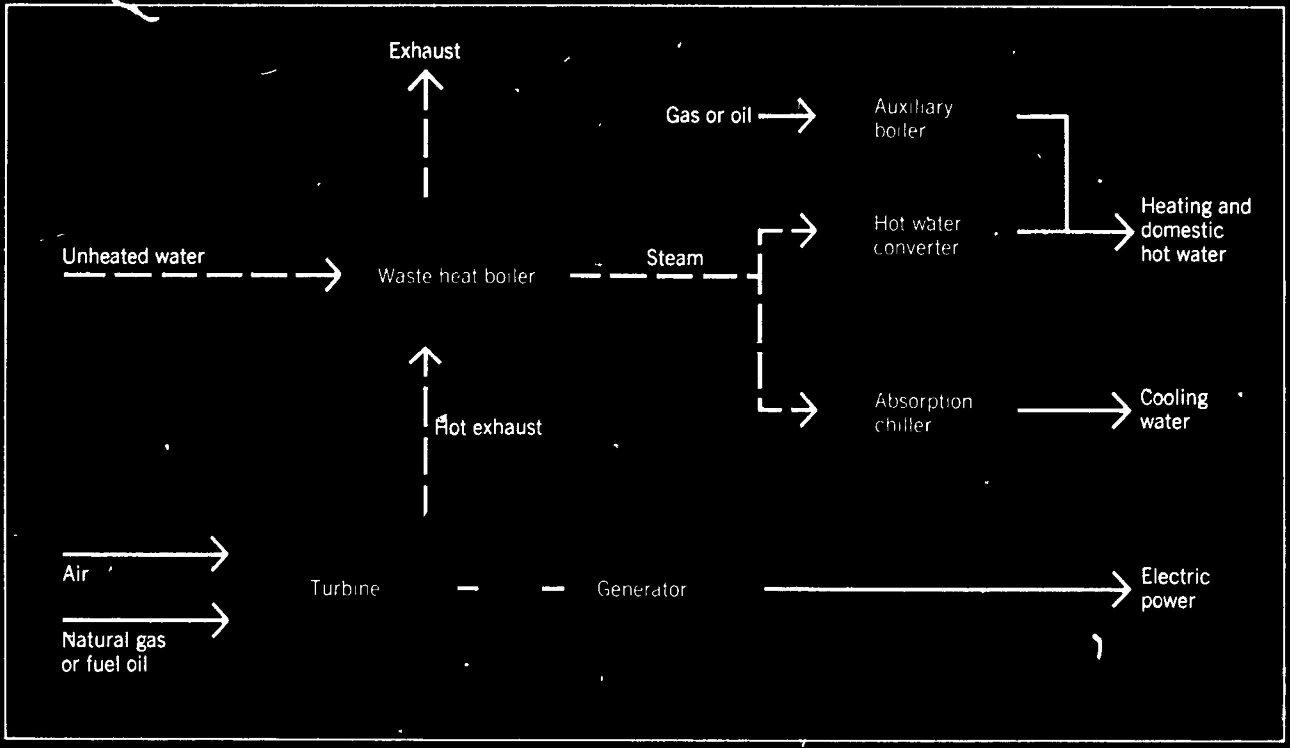
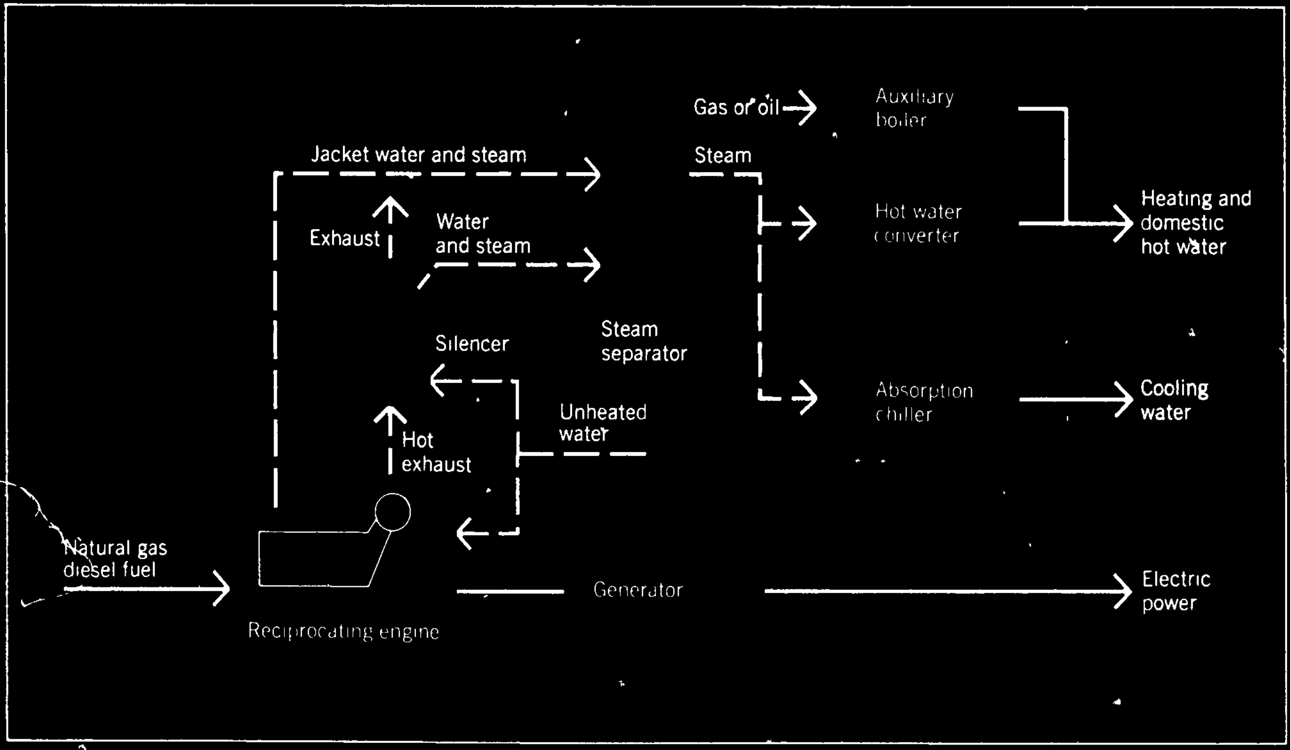
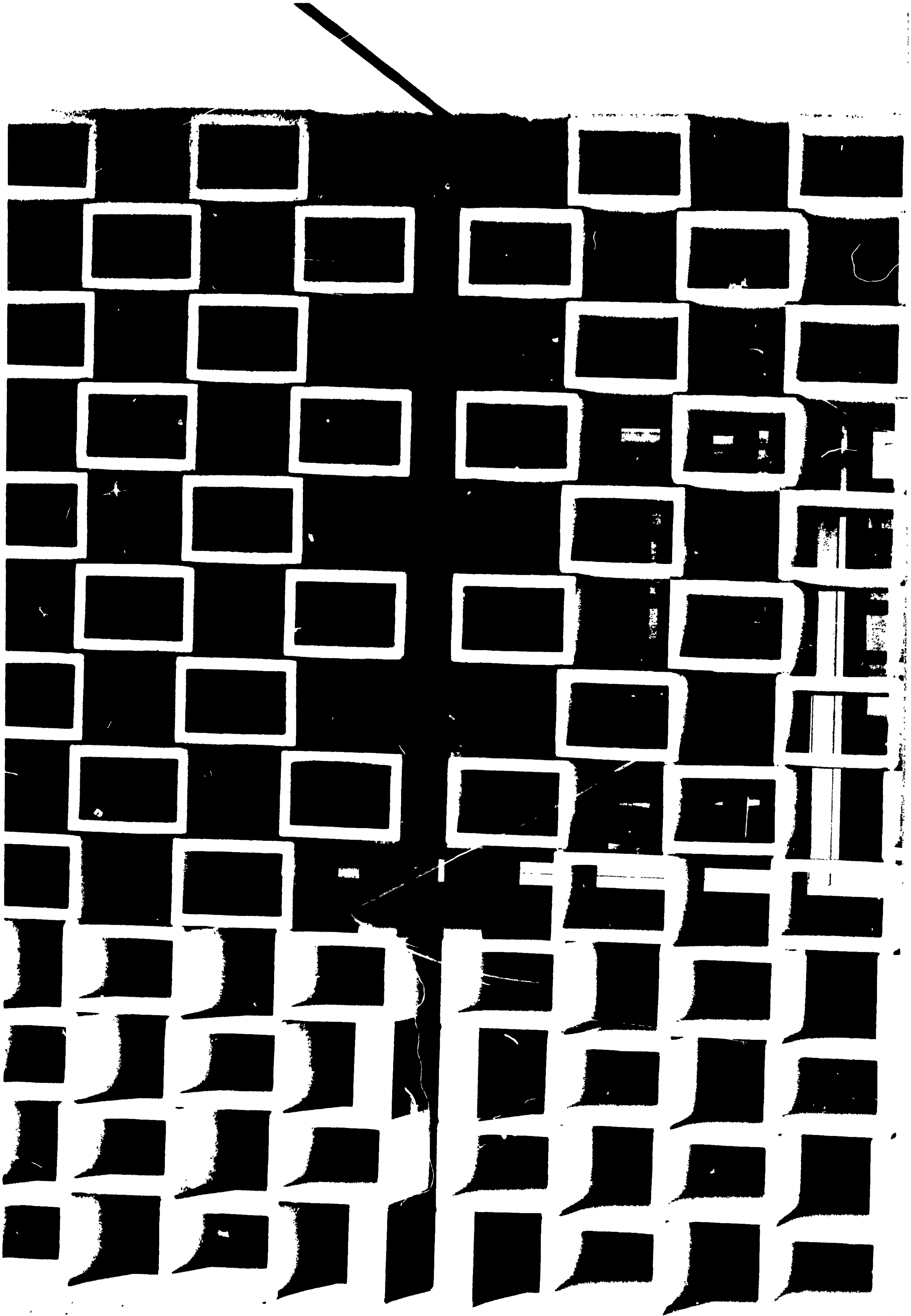


Figure 2. Total energy system using reciprocating engine





2. Two Case Studies

I. Msgr. O'Rafferty High School

Lansing, Michigan
Catholic Diocese of Lansing, Owner
Father Francis Martin, Superintendent
Mayotte-Webb, Architects
C.J.R. McClure & Associates, Inc.,
  Consulting Engineers
Elgin L. Clark, Inc., Associate Engineers

Background

Planned in 1962 and opened for classes in January of 1964, the Msgr. O'Rafferty High School in Lansing, Michigan, represents a total energy installation using natural gas as its primary fuel. It is one of a two-part school-building program to serve the parishes of Lansing and its growing suburbs. An identical school, Msgr. Gabriels High, is on the east side of town.

The west-side O'Rafferty school was designed for an initial enrollment of about 1,000 students in Grades 9 through 12, with separate faculty and classroom facilities for boys and girls. It is a compact, one-story, rectangular structure totaling 123,451 square feet, all of it air conditioned the year around. Its design not only features interior flexibility (class sizes may be as small as 15, as large as 120), but also permits future expansion to a total enrollment of 2,000 students. O'Rafferty provides 5,250 square feet of residential space for a small (6-man) teaching staff of Christian Brothers. The 6, along with 9 sisters and 17 lay teachers, comprise the students' faculty. Total cost of the school was just under $1,500,000—or approximately $11.50 per square foot.

Total Energy Installation

At O'Rafferty High School, the prime electrical generating equipment is powered by two natural-gas engines which are adequate for the school's present enrollment of 803 students. Provision has been made for the installation of a third engine-generator set to handle the power needs of a possible future expansion to 2,000 students.

Natural gas was chosen over diesel fuel because of its low cost in the Lansing area. However, should natural-gas costs increase in the future to an uneconomical level, the heads and pistons of both engines can be replaced and the entire system converted to diesel operation.

The gas engines power two 225-kilowatt generators which provide the electricity for the school's high-voltage fluorescent lighting system, plus its conventional 110-volt convenience outlets, and run the electric motors used in connection with the heating, cooling, and ventilating system. In addition, the same generators power a 450-kilowatt resistance heater which is used to artificially load the engines (create a power demand when lighting needs are low) and to augment the system's waste-heat recovery equipment during peak heating periods.

Both engines are water-cooled. The 240-degree F. water extracted from the cooling jackets is directed into flash tanks at low pressure. It instantly turns to steam which then is piped either to an absorption-chiller unit or to heat-exchangers for the school's hot-water heating system. Additional building heat is secured from jackets installed around the mufflers of both engines.

The school is not quite electrically self-sufficient, as a result of local code requirements. There is no technical reason why it could not have been. The local electric utility provides a small service to the faculty residence, plus power for exit lights and fire alarms.

Cost Data

The cost of the total energy installation at O'Rafferty is estimated to have been $80,000 more than the cost of a conventional heating and air-conditioning system designed to utilize purchased electrical energy. (Elgin L. Clark, Associate Engineer on the project, said "today it could have been done for $55,000—$25,000 less—because of new equipment and adaptation.") Roughly half of the added cost—or $39,000—went for the purchase, delivery, and installation of the engines and generating units. Another $30,000 went to purchase and install the piping, exchanger pumps, and similar peripheral equipment involved in the energy conversion processes.

However, the savings from the operation of the O'Rafferty total energy installation are estimated to run between $8,000 and $10,000 annually. This means recovering, within 10 years' time, the entire amount of the greater initial investment.

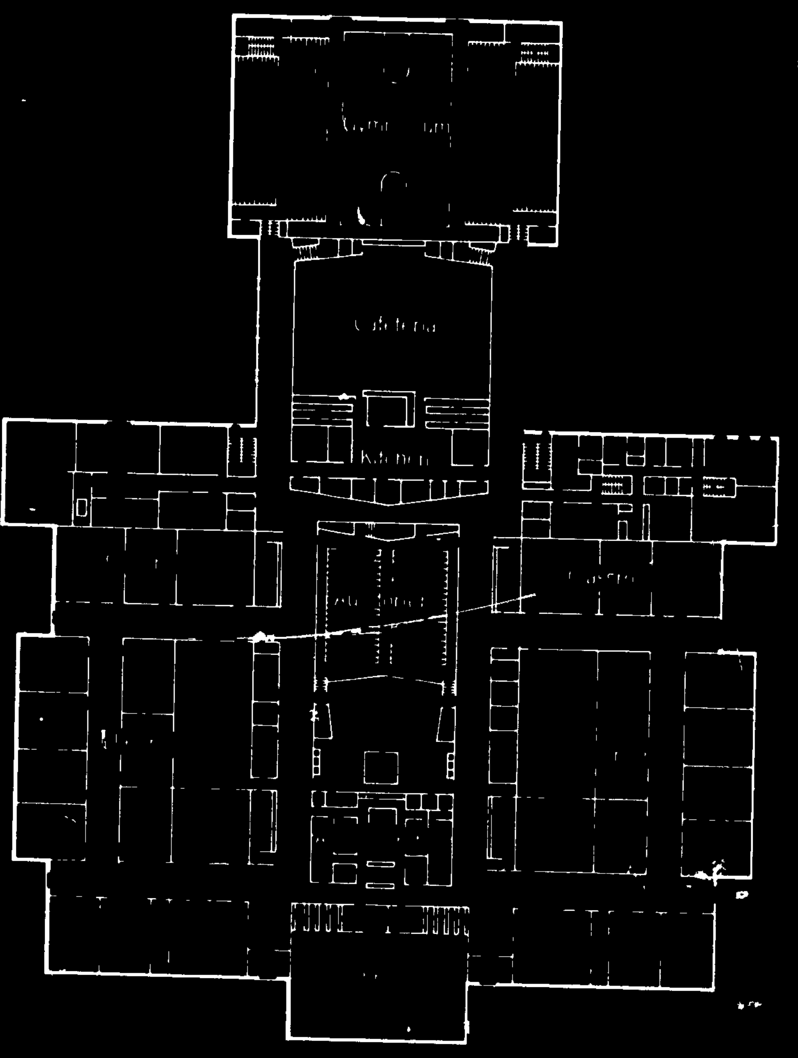


Figure 3 Plan Msg· O'Rafferty High School

II. McAllen High School

McAllen, Texas

S.P. Cowan, Superintendent
Zeb Rike, A.I.A., Architect
D. Dana Price, Consulting Engineer

Background

McAllen, Texas, is located in the heart of the Rio Grande Valley where the heat is enough to grow crops—and wilt humans—329 days of the year. It is, in short, a climate where air conditioning is more a necessity than a luxury in homes, cars, shops, and schools.

Opened in 1963, the 190,496-square-foot McAllen High School (expanded in August, 1964 to 212,096 square feet) is a compact, windowless, fully air-conditioned plant. It is also a total energy school, its entire cooling, heating, and electrical energy needs being supplied by two turbine-generators fired by natural gas. Since its opening, the school has been operated all year around except for three days during the summer. In fall, winter, and spring it serves as a high school for some 2,300 McAllen teen-agers; in the summer it accommodates 1,800 students for enrichment or remedial work. Also, the school is open three nights a week, 49 weeks a year, for various professional meetings, adult activities, and PTA meetings.

Except for a small area devoted to science labs on a second level, the school's 46 classrooms, 1,300-seat auditorium. 600-seat cafeteria, gym, shop, study hall, and library are all located on one level. Original cost of the school (which does not include the 21,600-square-foot addition of August, 1964) was close to $1,900,000—about $9.50 per square foot.

Total Energy Installation

At the heart of the McAllen High School total energy installation are two 1,100 horsepower gas turbines operating on natural gas at a pressure of 150 pounds per square inch.

Each of these turbines drives two electric generators in tandem. One is a 290 kilowatt generator supplying 840-cycle current for the school's fluorescent lighting. The other is a 450 kilowatt generator which provides 60-cycle current for conventional electric power applications in the school's convenience outlets, kitchen, shop, auditorium, et cetera. Since the energy output of one of the turbine-plus-two-generators units is enough to fulfill the school's normal energy needs, the two identical units are used alternately, and, in effect, one is always on standby.

The exhaust heat from the turbine (at 800 degrees F.) is fed into a heat-recovery boiler which not only effectively acts as an exhaust noise silencer, but also produces 6,700 pounds an hour of 15 psi (pounds per square inch) steam. The steam output is used in an absorption-chiller unit to produce 44 degrees F. chilled water for air conditioning. The balance—or whatever of the balance may be needed—is fed into hot-water converters and generators to produce hot water for heating purposes and for domestic hot-water requirements.

An auxiliary natural-gas boiler, capable of producing 4,800 pounds of steam per hour, is provided to supply peak-load demands and to allow for future expansion of the school plant.

One feature of the McAllen total energy installation is especially worth noting. With high speed turbines, the ability to develop high-frequency (840 cycles per second) energy for fluorescent lighting has produced collateral savings in the school's lighting costs. For the same light output, McAllen required 24 per cent fewer fluorescent fixtures than would have been needed with conventional 60-cycle current and, proportionately, considerably less heat is generated.

Cost Data

The cost of the two gas turbines and their related equipment for the McAllen school was just short of $250,000—about $180,000 more than the cost would have been for a conventional air-conditioning/heating system powered by energy purchased from outside sources.

However, a feasibility study conducted prior to construction by Consulting Engineer D. Dana Price estimated that the school's electric-power consumption would have meant a total annual bill for these services, if purchased from outside sources, of $64,474. Actual fuel costs during the first 18 months of the school's operation have averaged out at $13,280 per year—or a saving, via total energy, of some $51,200 per year over a conventional system. At this rate, the school can expect to recoup its entire total energy equipment investment in just under five years

Figure 4. Plan, McAllen High School

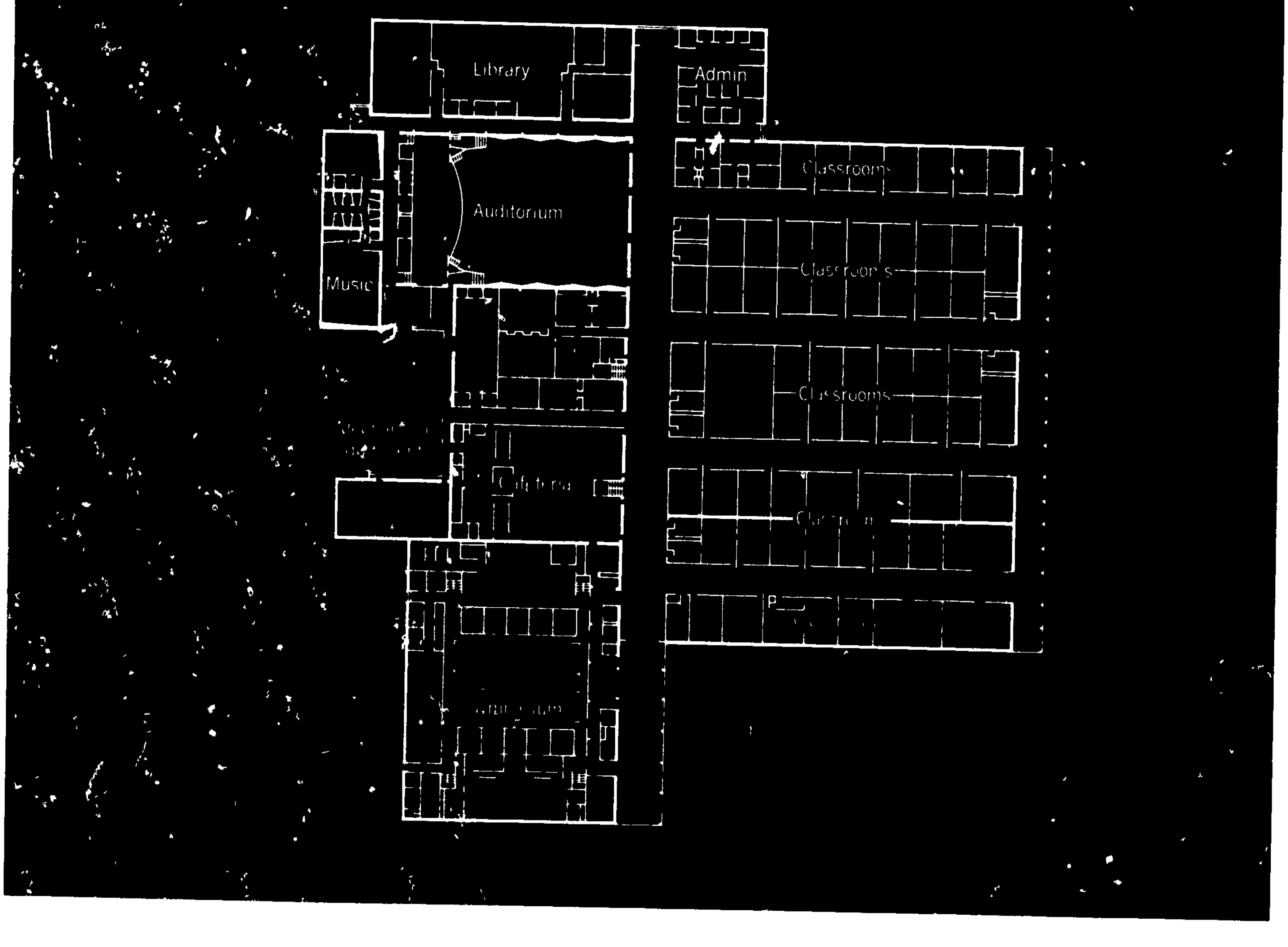


Figure 5. Schools with total energy installations

School	Architect	Mechanical Engineer	Size	Total energy plant description
Bergan High School Peoria, Illinois	Drake-O'Meara	C J R McClure & Associates	129,000 sq ft 1,200 students	Diesel engine generators with jacket water and exhaust heat recovery, 2 at 250 KW, 1 at 150 KW Steam absorption chiller—90 tons Reciprocating chiller—120 tons with 60 tons Equipped for heat pump operation Electric immersion heaters and hot water storage tank
Brady High School St Paul, Minn	Drake-O'Meara	C J R McClure & Associates	130,000 sq ft	Gas engine generators with jacket water and exhaust heat recovery, 3 totaling 625 KW Steam absorption chiller, no auxiliary boiler Electric immersion heaters and hot water storage tank
Costa High School Galesburg, Ill	West & Weber	West & Weber	44,000 sq ft 330 students	Diesel engine generators with jacket water and exhaust heat recovery, 1 at 150 KW, 1 at 100 KW Hot water absorption chiller—90 tons Auxiliary boiler and hot water storage tank
John F Kennedy Junior High School Rockledge, Florida	William Faust	Frank B Wilder & Associates	105,000 sq ft 1,500 students	Gas engine generators with jacket water and exhaust heat recovery, 2 at 225 KW, 1 at 25 KW (stand by) Steam absorption chiller—110 tons Auxiliary boiler and auxiliary electric cooling units for peak loading
Gabriels High School Lansing, Mich	Manson, Jackson & Kane	Elgin Clark C J R McClure & Associates	125,000 sq ft 1,000 students	Gas engine generators with jacket water and exhaust heat recovery, 2 at 225 KW Steam absorption chiller—260 tons Auxiliary boiler Electric immersion heaters and hot water storage tank
Hillcrest Junior High School Jasper Place, Alberta, Canada	John McIntosh	Vinto Engineering Ltd Jarvis Engineering	67,000 sq ft 880 students	Gas engine generators with jacket water and exhaust heat recovery, 2 at 300 KW Steam absorption chiller—156 tons Auxiliary boiler
Institute of Gas Technology Chicago, Ill	Schmidt, Garden & Erikson	Schmidt, Garden & Erikson		Operating test laboratory 1 gas turbine generator, 310 KW (420 & 60 cps) 4 gas engine generators with jacket water and exhaust heat recovery, 2 at 135 KW, 1 at 125 KW (420 cps), 1 at 75 KW High frequency power (420 cps) is generated for lighting Steam absorption chiller—325 tons Waste heat boiler for turbine exhaust Auxiliary boiler
McAllen High School McAllen, Texas	Zeb Rike	D Dana Price	212,000 sq ft 2,300 students	Gas turbine generator, 2 at 750 KW (840 cps and 60 cps) High frequency power is generated for lighting Absorption chiller—467 tons Waste heat boiler and auxiliary boiler
Msgr O'Rafferty High School Lansing, Mich	Mayette-Webb	Elgin Clark C J R McClure & Associates	125,000 sq ft 1,000 students	Gas engine generators with jacket water and exhaust heat recovery, 2 at 225 KW Steam absorption chiller—260 tons Auxiliary boiler Electric immersion heaters and hot water storage tank

Figure 6. Weather zones

3. Guidelines to Total Energy Feasibility

The choice of a total energy system is heavily dependent on individual local conditions. Its efficacy will be determined by the size and projected use of the school plant and by local rates for fuel and electricity. These factors must be investigated and weighed in a feasibility study as a first step toward a decision.

Under What Conditions is Total Energy Feasible?

In general, in order for a total energy installation to make economic sense, three criteria must be met:

First, there should be the expectation of a high and fairly constant electric power demand over an extended portion of the day and over most of the year. Power generation equipment maintains its highest efficiency when operated at constant demand levels over long periods of time. The school or college with extensive evening and summer programs will therefore obtain the best return on its investment in on-site generating equipment.

Second, the building should function so that demands for heating or air conditioning will occur simultaneously with, and in relative proportion to, the demand for electricity. In this way, immediate use of waste-heat by-products is assured. This, in effect, presupposes air conditioning of the building for year-round use. If air conditioning is not even being considered, for climatic or other reasons, then a total energy system is almost certainly uneconomic since the only possible use for waste-heat by-products would occur during the heating season.

Third, the gas or liquid fuel rates in the area should be low enough to compete with prevailing electric rates. This sounds obvious; the catch, however, is in the definition of the word "compete." In cases where local electric rates are known to be well below the national average, and gas or oil rates known to be well above, total energy is bound to be a loser. Reverse the conditions, and it doesn't take a mathematical genius to decide that the fuel-cost criterion has been met. The difficulty occurs in areas where the spread between electric rates and gas or liquid fuel costs is not so marked as to give one a head-and-shoulders advantage over the other. Under these conditions, a careful analysis of cost data for each type of energy source will permit a reasoned decision as to whether this criterion has been met.

Since the cost of a total energy installation will raise the construction cost of a school or college building by two to five per cent over the cost of the same building conventionally air conditioned, the economies of total energy are of great interest to school planners. Given the right conditions (i.e., all three criteria met), this added first cost can be amortized swiftly through savings in operating costs, and a total energy system will not only pay for itself in a short period, but thereafter will put money into the bank every year.

How to Conduct a Preliminary Feasibility Study

An examination of current total energy practices and an extensive survey of plants now in operation have enabled the development of simplified feasibility curves, which are included in this report, together with instructions for their use and interpretation. Using these curves in conjunction with information readily available in the *early* stages of project planning, an architect or engineer can derive an indication of the feasibility of total energy for a given project.

All that must be known in order to determine the degree of feasibility with these curves is (1) the gross area of building space involved, (2) anticipated occupancy programs, and (3) local fuel and electricity costs. The results (given in terms of rate of return on the added investment) will answer the question: Is a total energy system feasible for the project at hand?

If it turns out to be definitely *not* feasible, then no more time need be spent in pursuit of the unattainable. If it turns out to be definitely feasible, then additional effort can be expended where it is most needed—in selecting the optimum system for the project. If it turns out to be marginally feasible, additional data will have to be assembled and evaluated in order to reach a final decision.

A note of warning concerning oversimplification of this task: while the feasibility curves provided are devised for quick and easy analysis, we do not intend this as a "do-it-yourself" kit enabling school superintendents or their business managers to arrive at major engineering decisions without the guidance of experienced professional consultants. The proper evaluation of this data and the analysis of feasibility require the attention of competent engineering advisers.

Should a preliminary examination prove affirmative and more detailed engineering studies be authorized, further pertinent data and technical information are provided in this booklet to assist design engineers. The following section contains guidelines for total energy plant design and equipment selection.

Basis for Analysis

The fundamental approach used in this report to evaluate the feasibility of total energy was to compare two sets of hypothetically equivalent schools or colleges, one set with a conventionally powered heating and air-conditioning plant and the other with a total energy plant. Pairs of schools identical in respect to program, size, layout, construction, location, hours of occupancy, and energy requirements were then compared.

For the *conventional school or college,* electric power was assumed to be purchased from the public utility with heating provided by a boiler (hot water or steam) and cooling by chilled water from an absorption refrigeration machine operating in conjunction with the boiler. Steam-driven absorption units as opposed to electrically driven compressor-chillers were assumed, since the consideration of total energy as economically feasible implies that fuel rates (gas or oil) are low and purchased electricity rates high. (A comparative study of absorption refrigeration and electrically driven compressor-chillers is shown in Appendix A.)

For the *total energy plant,* the most economical combination of reciprocating engines or turbines, controls, and heat-recovery equipment was selected to provide for the heating and cooling demand in excess of that available from the waste-heat recovery equipment. An absorption refrigeration machine similar to that for the conventional plant was assumed. Once outside the central equipment room, electric power, hot water or steam, and chilled water would be distributed throughout the project by the same system as with the conventional plant.

For this analysis, the United States was considered divided into three zones based upon weather characteristics, since different heating and cooling seasons will affect the selection of the total energy system and the performance of the plant. The zones are shown in Figure 6 and are based upon degree days for heating and outdoor winter design temperatures.

Within this framework of climate zones, different size categories of schools and colleges were analyzed for the feasibility of a total energy installation compared to an equivalent conventional design. The basis of this comparison was *total owning and operating* costs for each installation, as determined by an examination of current design practices as well as extensive surveys of actual recorded data. Through a series of calculations, a set of curves was developed which relate the rate of return on the added investment required for a total energy installation to the prevailing costs of gas, oil, and electricity. *It is this rate of return on added investment which becomes the true measure of total energy feasibility.* In this way, a comparison is established based on long-range economics rather than on the traditional,

$$\text{RATE OF RETURN } \textit{equals } \frac{\text{Annual savings yielded by total energy installation (\$)}}{\text{Added investment in total energy (\$)}}$$

but insufficient, measurement of initial costs alone.

Based on the prevailing investment picture at the time of this writing, rates of return can be divided into three categories of feasibility:

(1) Definitely feasible—rate of return greater than eight per cent.

(2) Marginal—rate of return between six per cent and eight per cent (more detailed analysis in terms of specific project requirements and building design required).

(3) Not feasible—rate of return less than six per cent.

Any subsequent investigation of total energy feasibility must be determined in comparison with prevailing investment conditions at the time.

The Following Example Illustrates the Use of These Curves

Consider a 100,000-square-foot high school in an Ohio suburb. The school is to have a full summer program and an adult education program two nights per week. The entire building is planned for air conditioning.

For this hypothetical example it is assumed that electric power in the area is available at an average rate of 2.5¢/KWH (per kilowatt hour). Natural gas at approximately 1 psi (pound per square inch) is available at an average "firm" rate of 55¢/MCF (thousand cubic feet) and diesel oil can be purchased at 11¢/gal.

This school would be in Climate Zone II with the program of occupancy B-1, and the appropriate graph is selected.

For gas at 55¢/MCF, follow up to the curve for electricity at 2.5¢/KWH and, reading to the left, the expected rate of return for the added investment in the total energy plant is 11 per cent. In considering oil as a possible fuel, enter at the cost of 11¢ gal. and proceed up to the curve of electricity at 2.5¢/KWH. Reading to the left, the rate of return is 7.5 per cent.

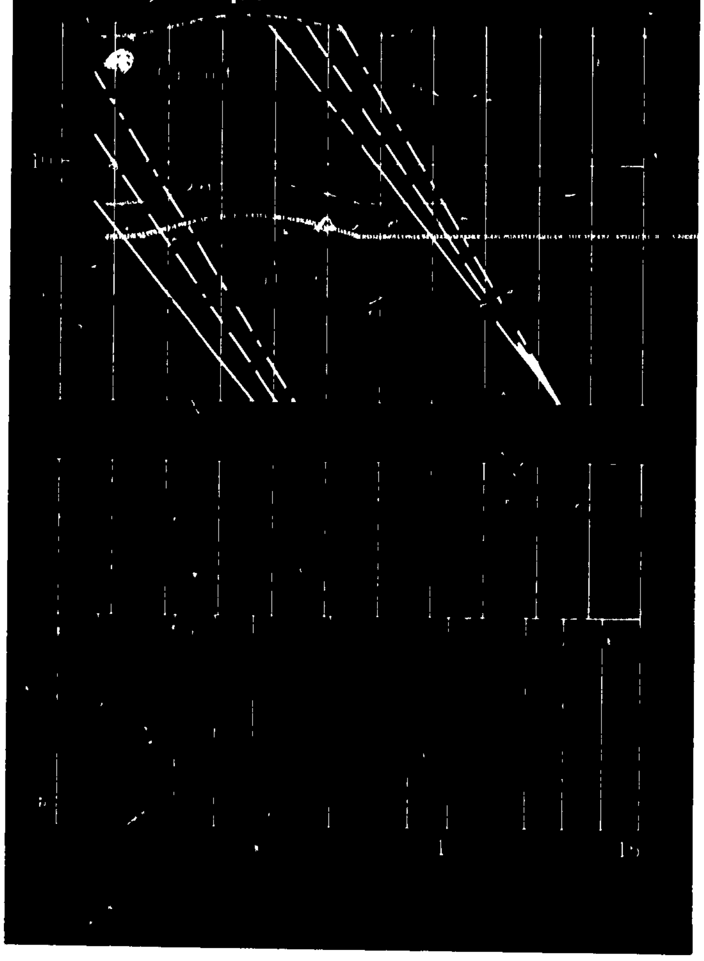
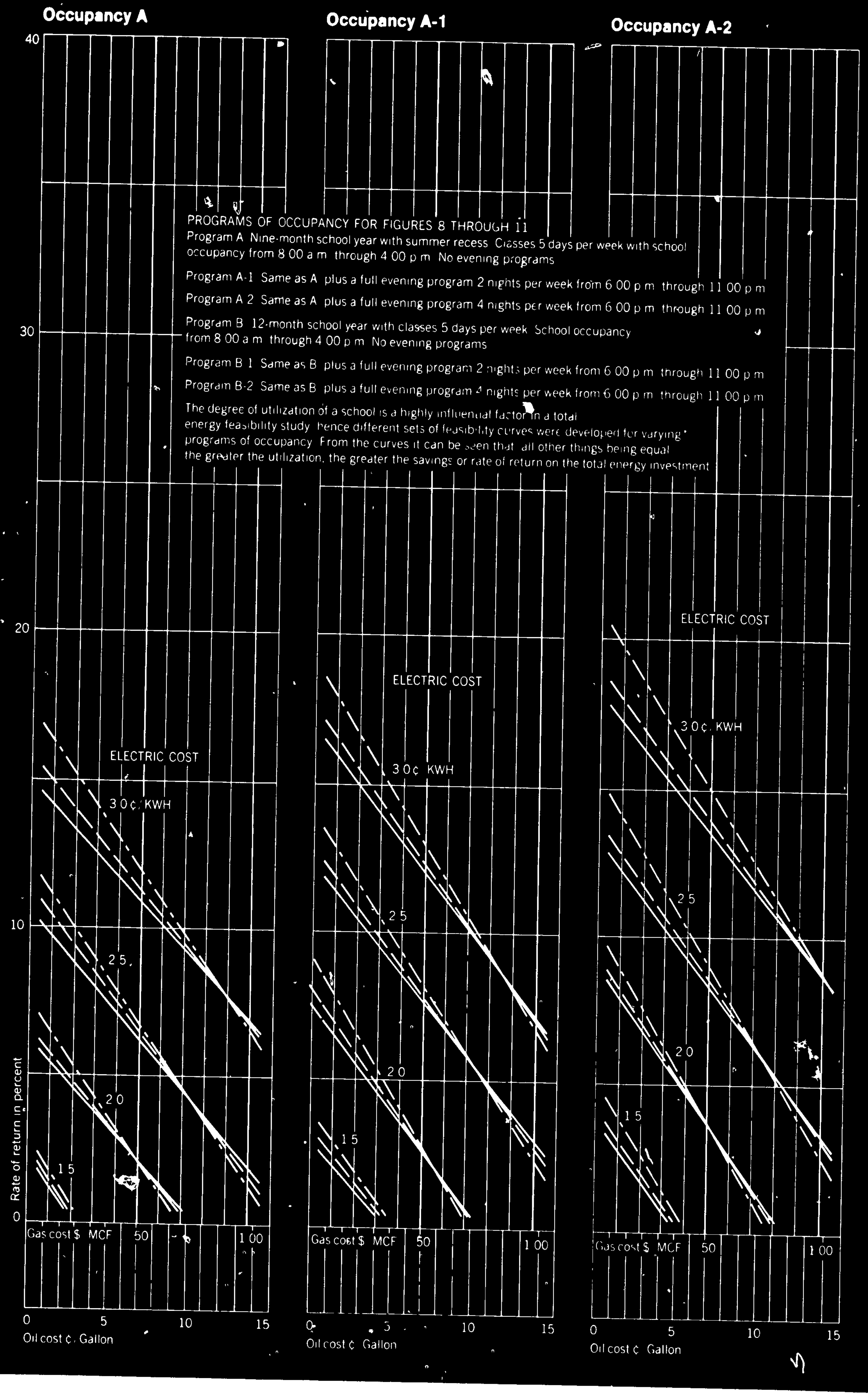


Figure 7. Detail from feasibility chart for 100,000 square foot school

Thus, within this rate structure, total energy would be feasible (return on investment higher than 8 per cent) if gas is the fuel. However, oil presents only a marginal case (between 6 per cent and 8 per cent) and requires a more detailed study based on specific design requirements before a decision, for or against total energy using oil, can be made. On the basis of favorable results, total energy should be pursued seriously, with the architect and consulting engineer developing plans for the building incorporating a total energy plant. When preliminary plans and a specific program for the project have been developed, a detailed economic analysis of the total energy plant should be performed to determine more precisely the costs involved and the anticipated savings. Should the results of this analysis substantiate the preliminary indications in a more concrete fashion, final plans and specifications can be prepared.

Where ANNUAL SAVINGS *equals* Annual cost of purchased power, conventional system
minus Annual cost of fuel for on-site power generation, total energy system
minus Annual additional maintenance cost, total energy system
minus Annual depreciation, interest, and insurance on added investment, total energy system
plus Annual cost of fuel saved by recovered heat for heating and air conditioning, total energy system

FIGURE 8. TOTAL ENERGY FEASIBILITY CURVES—100,000 SQUARE FOOT SCHOOL



PROGRAMS OF OCCUPANCY FOR FIGURES 8 THROUGH 11

Program A. Nine-month school year with summer recess. Classes 5 days per week with school occupancy from 8:00 a.m. through 4:00 p.m. No evening programs.

Program A-1. Same as A, plus a full evening program 2 nights per week from 6:00 p.m. through 11:00 p.m.

Program A-2. Same as A, plus a full evening program 4 nights per week from 6:00 p.m. through 11:00 p.m.

Program B. 12-month school year with classes 5 days per week. School occupancy from 8:00 a.m. through 4:00 p.m. No evening programs.

Program B-1. Same as B, plus a full evening program 2 nights per week from 6:00 p.m. through 11:00 p.m.

Program B-2. Same as B, plus a full evening program 4 nights per week from 6:00 p.m. through 11:00 p.m.

The degree of utilization of a school is a highly influential factor in a total energy feasibility study; hence different sets of feasibility curves were developed for varying programs of occupancy. From the curves it can be seen that, all other things being equal, the greater the utilization, the greater the savings or rate of return on the total energy investment.


Zone I
Zone II
Zone III
MCF—thousand cubic feet
KWH—kilowatt hour
Occupancy B
Occupancy B-1
Occupancy B-2
40
30
20
10
0
Rate of return in percent
ELECTRIC COST
3 0¢/KWH
2 5
2 0
1 5
Gas cost $/MCF
50
1 00
Oil cost ¢/Gallon
0
5
10
15

FIGURE 9. TOTAL ENERGY FEASIBILITY CURVES—300,000 SQUARE FOOT SCHOOL

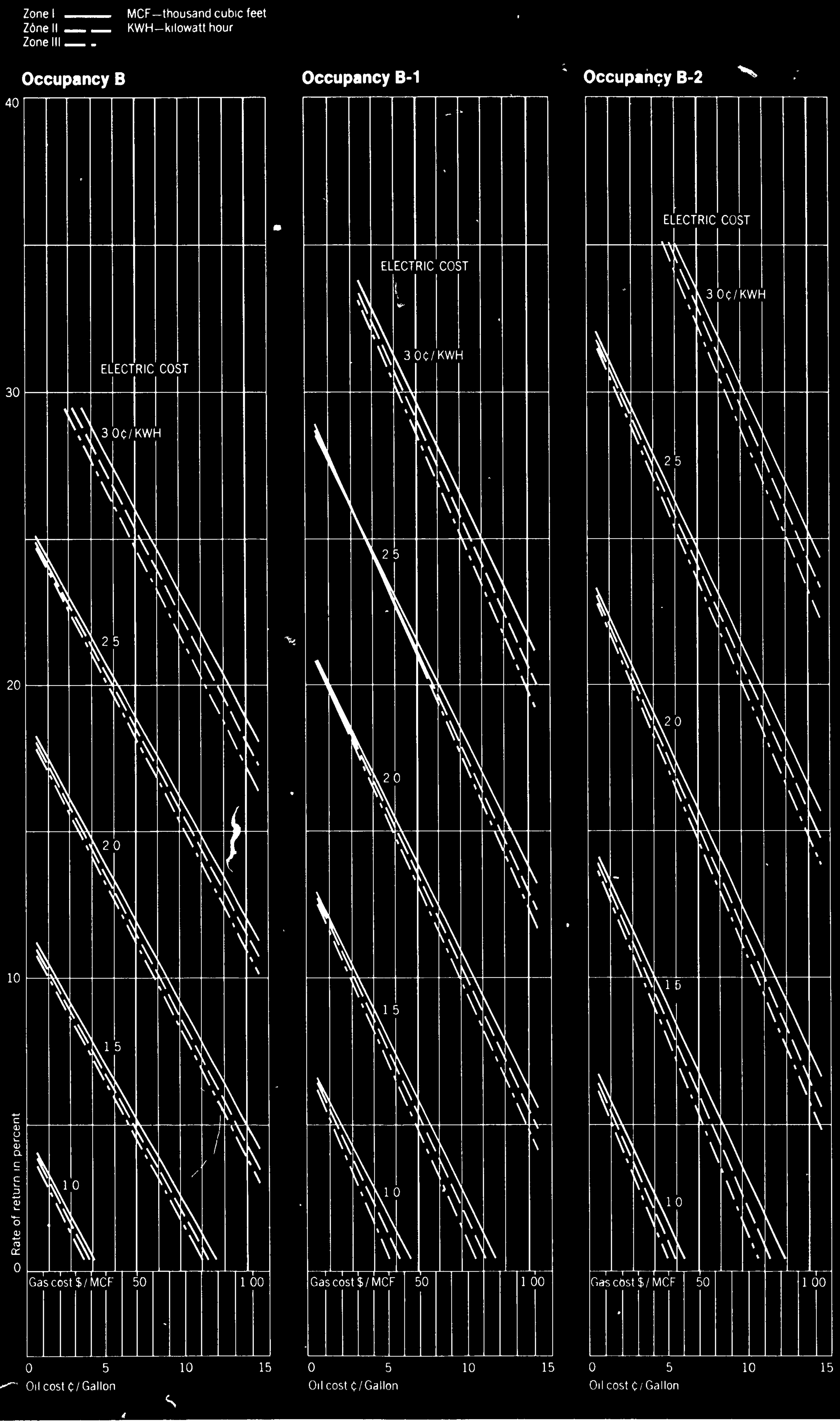
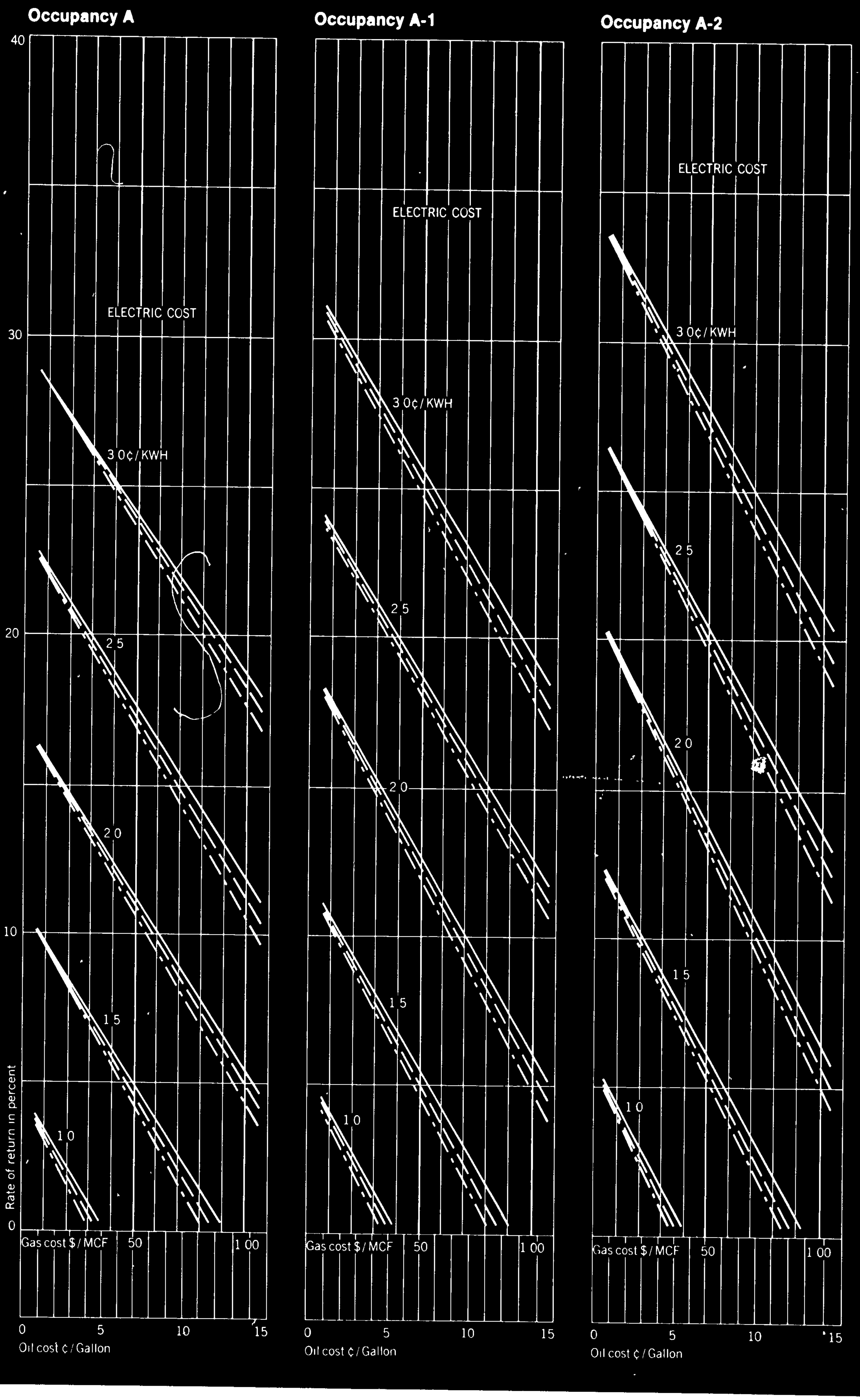

Zone I
Zone II
Zone III
MCF—thousand cubic feet
KWH—kilowatt hour
Occupancy B
Occupancy B-1
Occupancy B-2
ELECTRIC COST
3 0¢/KWH
2 5
2 0
1 5
1 0
40
30
20
10
0
Rate of return in percent
Gas cost $/MCF
50
1 00
Oil cost ¢/Gallon
0
5
10
15

FIGURE 10. TOTAL ENERGY FEASIBILITY CURVES—500,000 SQUARE FOOT COLLEGE



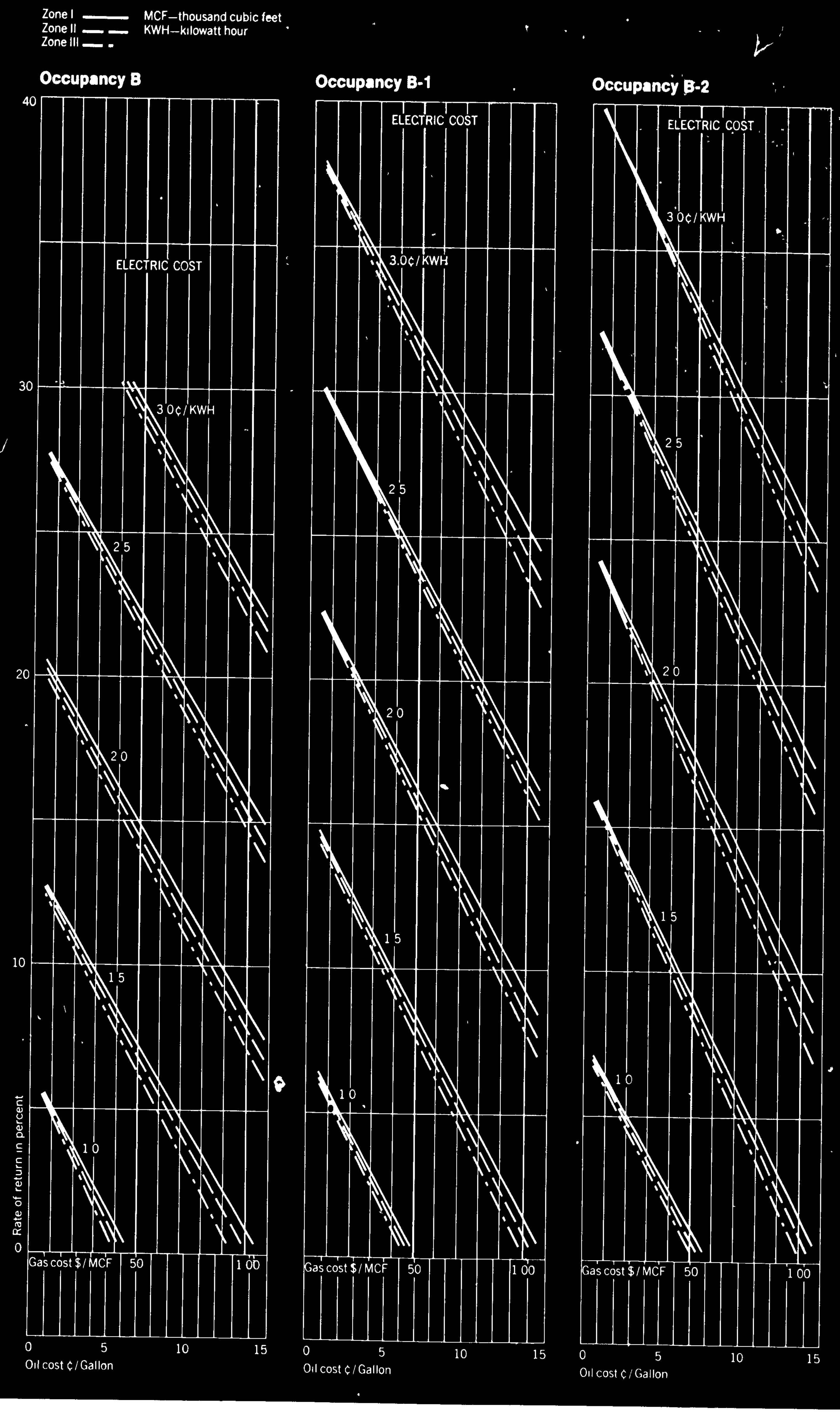
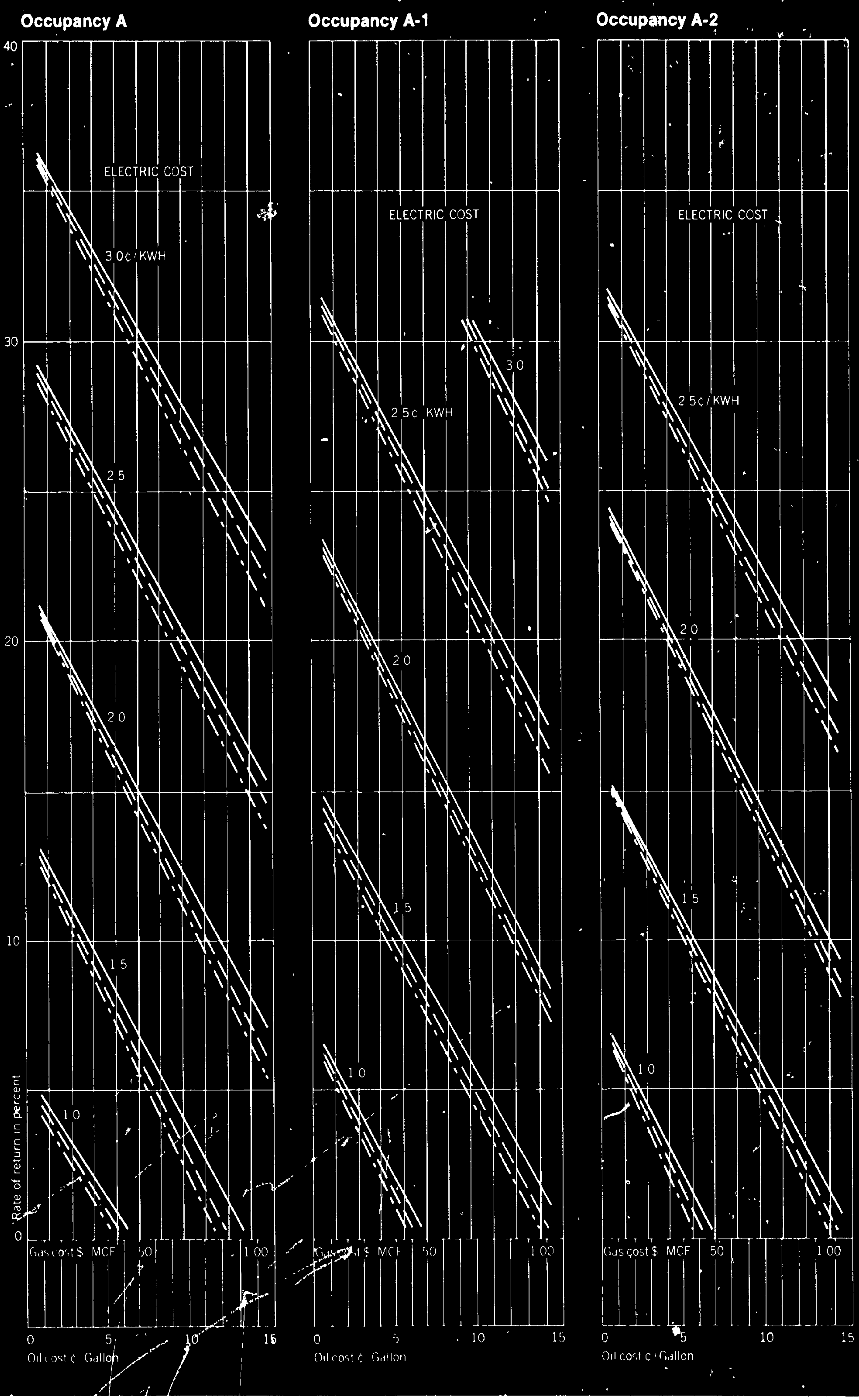
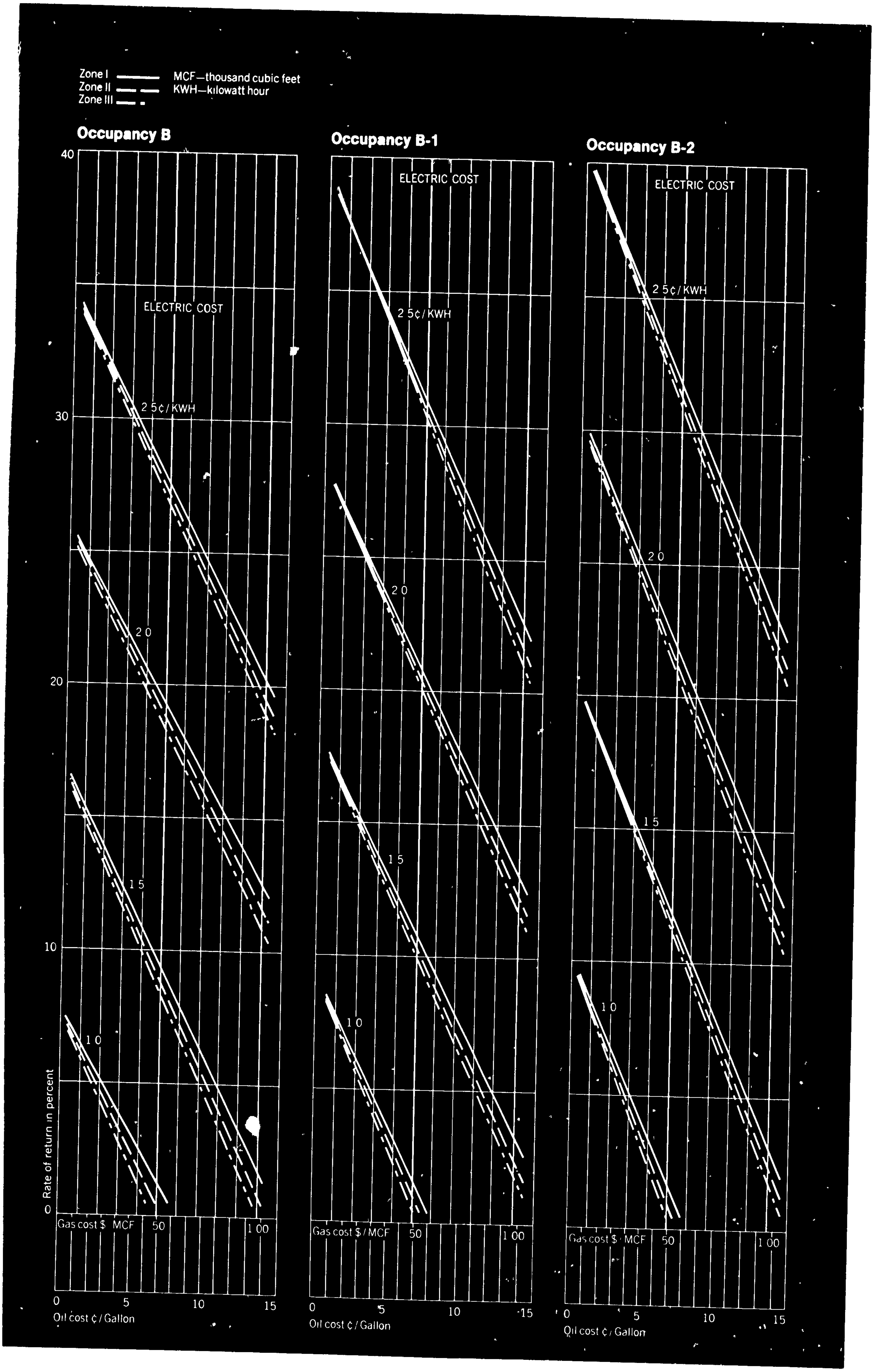
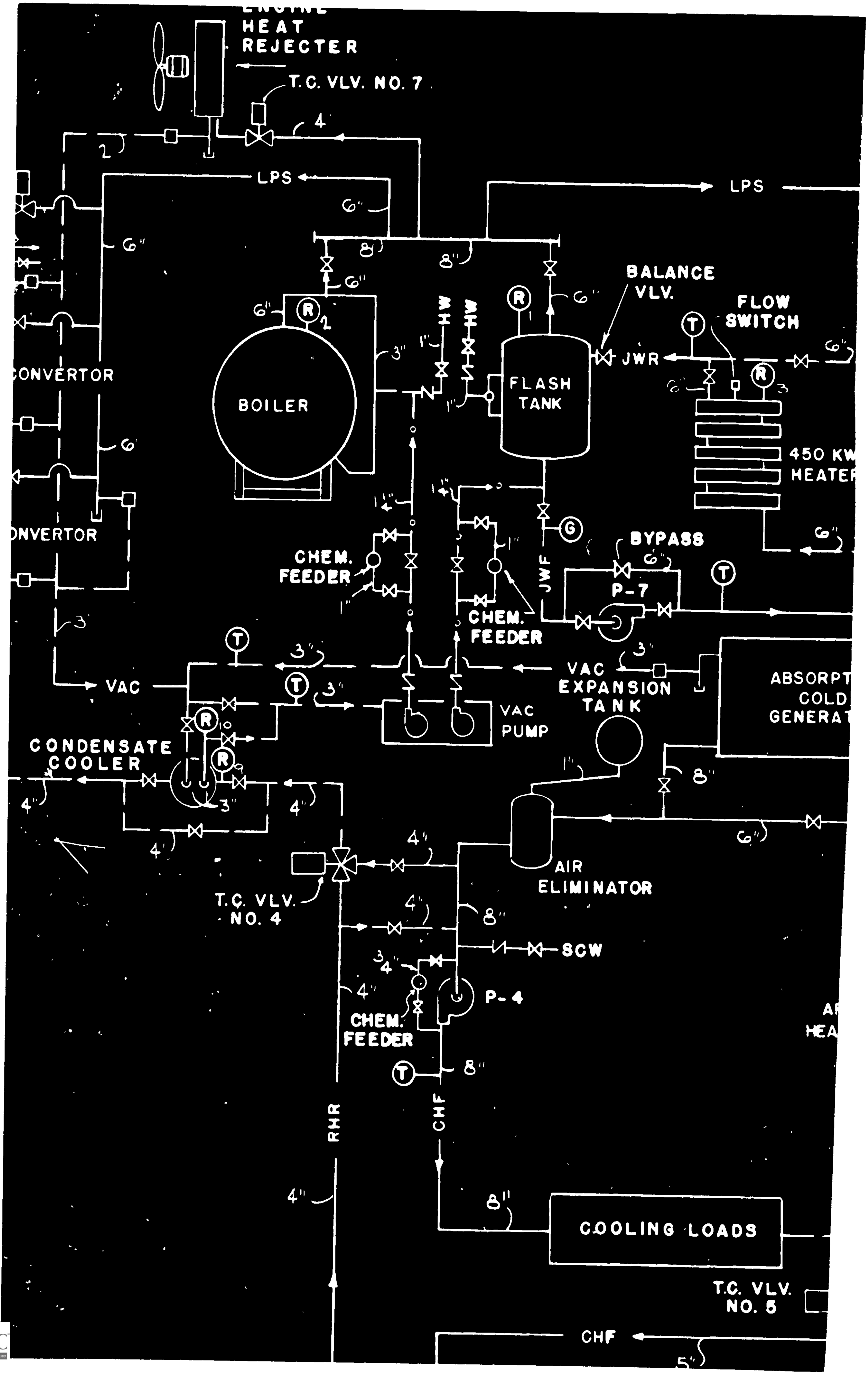

Zone I
Zone II
Zone III
MCF—thousand cubic feet
KWH—kilowatt hour
Occupancy B
Occupancy B-1
Occupancy B-2
ELECTRIC COST
3.0¢/KWH
2 5
2 0
1 5
1 0
40
30
20
10
0
Rate of return in percent
Gas cost $/MCF
50
1 00
Oil cost ¢/Gallon
0
5
10
15

FIGURE 11. TOTAL ENERGY FEASIBILITY CURVES—1,000,000 SQUARE FOOT COLLEGE




Zone I
Zone II
Zone III
MCF—thousand cubic feet
KWH—kilowatt hour
Occupancy B
Occupancy B-1
Occupancy B-2
ELECTRIC COST
2 5¢/KWH
2 0
1 5
1 0
Rate of return in percent
0
10
20
30
40
Gas cost $ MCF
50
1 00
0
5
10
15
Oil cost ¢/Gallon


HEAT
REJECTER
T.C. VLV. NO. 7
4"
2"
LPS
6"
LPS
8"
8"
6"
6"
6"
R 2
R 1
HW
HW
1"
1"
3"
BOILER
FLASH
TANK
BALANCE
VLV.
JWR
FLOW
SWITCH
T
R 3
6"
6"
450 KW
HEATER
6"
CONVERTOR
6"
CONVERTOR
3"
1¼"
1¼"
1"
CHEM.
FEEDER
1"
CHEM.
FEEDER
JWF
G
BYPASS
6"
P-7
T
T
3"
VAC
3"
T
3"
VAC
EXPANSION
TANK
ABSORPT
COLD
GENERAT
VAC
PUMP
R 10
R 9
CONDENSATE
COOLER
4"
3"
4"
4"
1"
8"
6"
AIR
ELIMINATOR
4"
T.C. VLV.
NO. 4
4"
8"
SCW
¾"
P-4
CHEM.
FEEDER
4"
T
8"
RHR
CHF
AI
HEA
4"
8"
COOLING LOADS
T.C. VLV.
NO. 5
CHF
5"

4. Designing the Plant and Selecting Equipment

ELECTRICAL LOAD PROFILE ANALYSIS

The first step in any total energy design is an analysis of electrical loads and load profiles. A load profile is the variation of the load demand as a function of time, showing graphically how the demand varies throughout a 24-hour day, a week, a month, or a year. The length of time chosen is determined by the extent of the analysis. For the purposes of schools and colleges, typical 24-hour days for various times of the year should be sufficient. The electric load profile is the key to selection of the electric power generating components. It generally depicts the hourly variation in kilowatt demands.

A fundamental characteristic of prime-mover power generating equipment is that it operates most efficiently when the unit is loaded to more than 60 per cent of its rated capacity. Since the electric load in schools and colleges varies for different conditions of occupancy, the most efficiently designed total energy plant would be one which utilizes generating sets sized so that combinations of the sets are always operating as nearly as possible to full rated capacity. Careful analysis of the electrical demands is critical so as not to overestimate peak requirements. If an excessive allowance is made for safety factors, it will be reflected in higher cost of total energy equipment, which increases almost directly with the electrical load. If certain school equipment is operated intermittently during peak electrical load periods and can be run by energy other than electricity to avoid impractical loading of the engine-generators, the other energy source should be considered. Examples would be cooking equipment or booster heaters for dishwashers.

From the load profiles shown in Figures 12, 13, and 14 for schools of 100,000, 200,000, and 300,000 square feet and colleges of 500,000 and 1,000,000 square feet, it can be seen that for a typical weekday the load stays at a maximum level during the hours of 8:00 a.m. to 4:00 p.m. Afterward the load drops off to handle only the after-school extracurricular activities and then falls to the minimum night level. In schools where evening classes are held, the late night load may rise to near the daytime level. On weekends and during vacations, the electric demand stays at the minimum level essential for lighting in passageways and for mechanical and electrical auxiliary equipment such as pumps, small refrigeration units, clocks, intermittent fan operation, etc. On certain occasions the gymnasium or auditorium will be in use for special events, thus causing a slight increase in the demand above the minimum, but without the need for lighting the bulk of the academic areas, so this demand is at an intermediate level. Colleges have, in the early evenings, the demand of the dormitories, the library, and special study areas prior to assuming the minimum night load.

The air-conditioning season requires additional capacity to run auxiliary equipment in the central plant, such as the cooling tower pump and fan, solution pumps on the absorption unit, and chilled water pumps. Added electric load is also required by increased fan horsepower during the cooling season. This is reflected in the profiles during the occupied periods.

A series of prime mover-generator components or modules should be selected so that they match those loads which exist for the longest periods of time during the year. These periods appear to be the normal daytime hours of maximum loading and the unoccupied hours of minimum loading. The largest modules which will still permit operation at maximum efficiency during the greatest number of operating hours should be selected. The simplest and most flexible system would be comprised of equal size modules. Standby requirements dictate that if any module were to be out of service there would be enough capacity in those remaining on-line to carry the maximum load. The likelihood of more than one module being out of

Figure 12. Electrical load profiles for 100,000 and 200,000 square foot schools

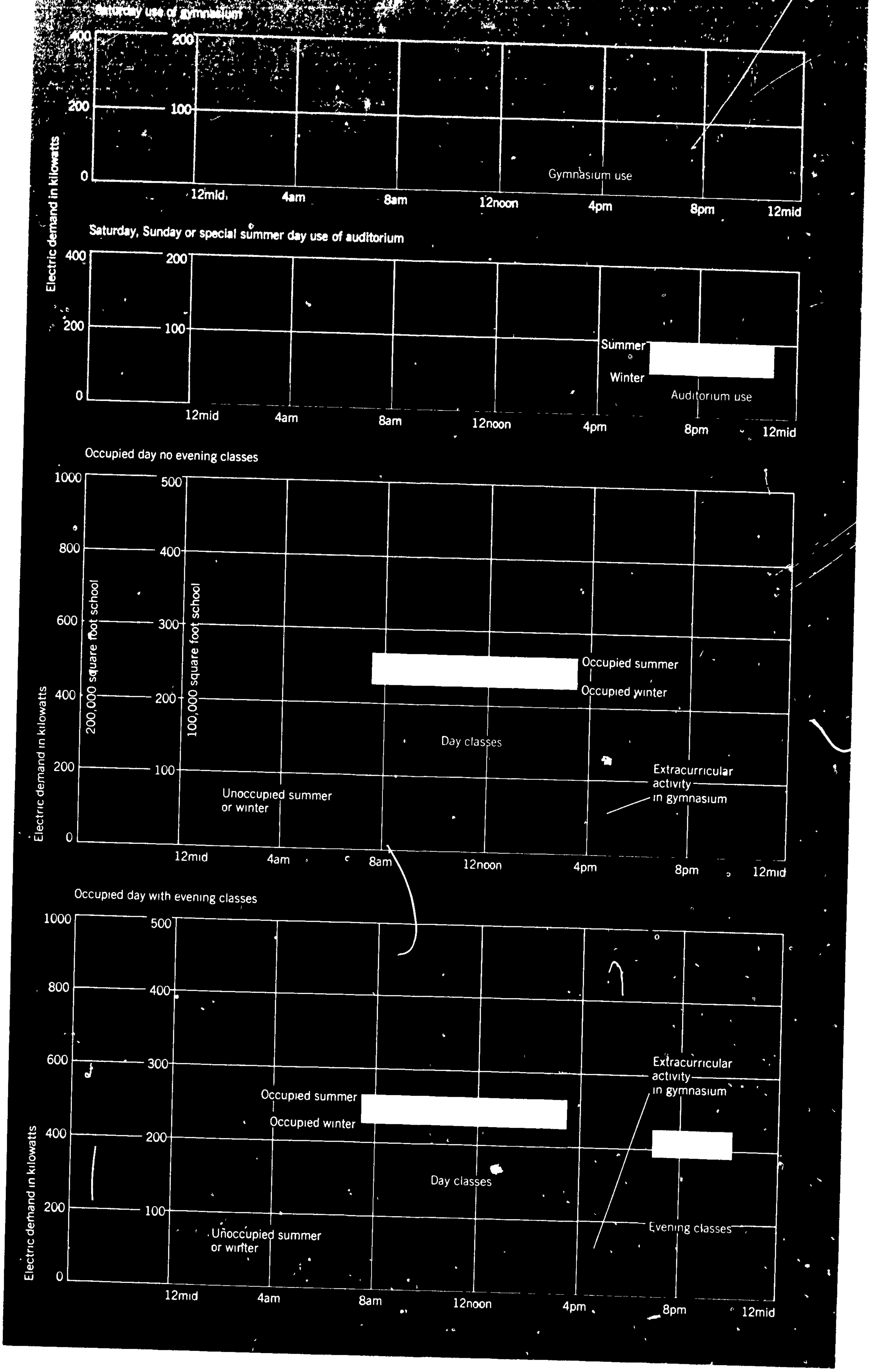
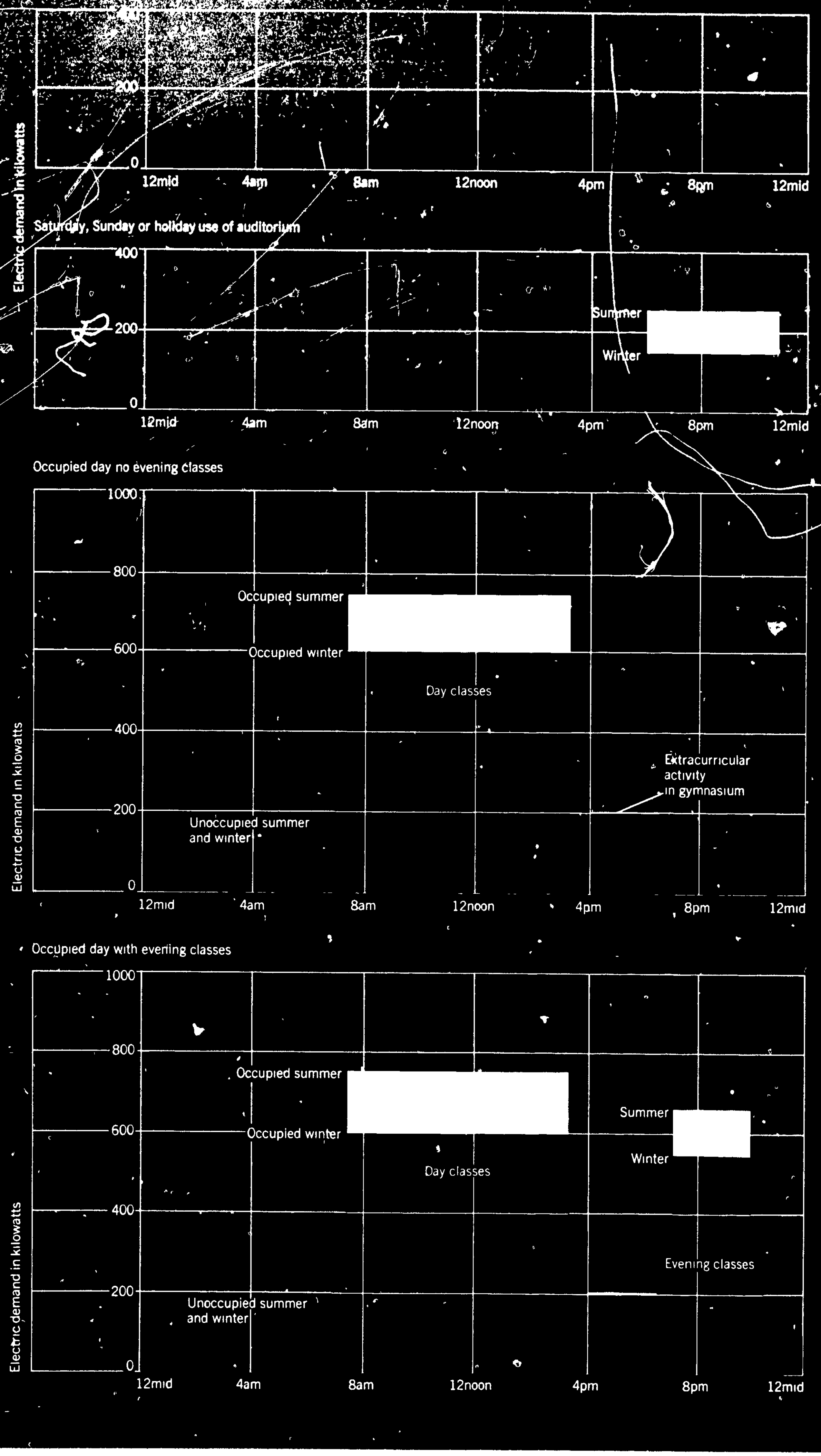


Figure 13. Electrical load profiles for 300,000 square foot school



Saturday use of gymnasium

Saturday, Sunday or holiday use of auditorium

Occupied day no evening classes

Occupied day with evening classes

Figure 14. Electrical load profiles for colleges, 500,000 and 1,000,000 square feet

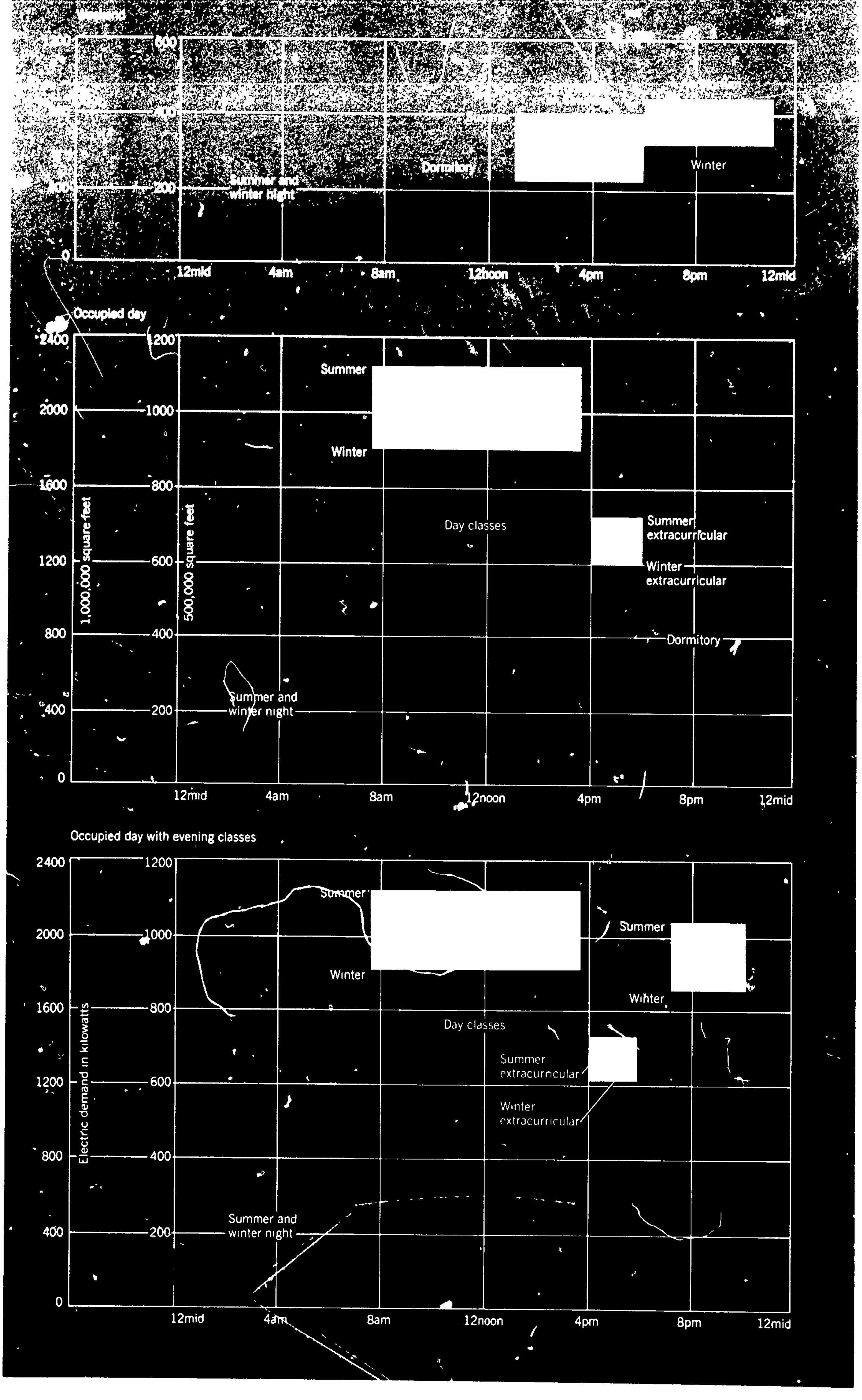
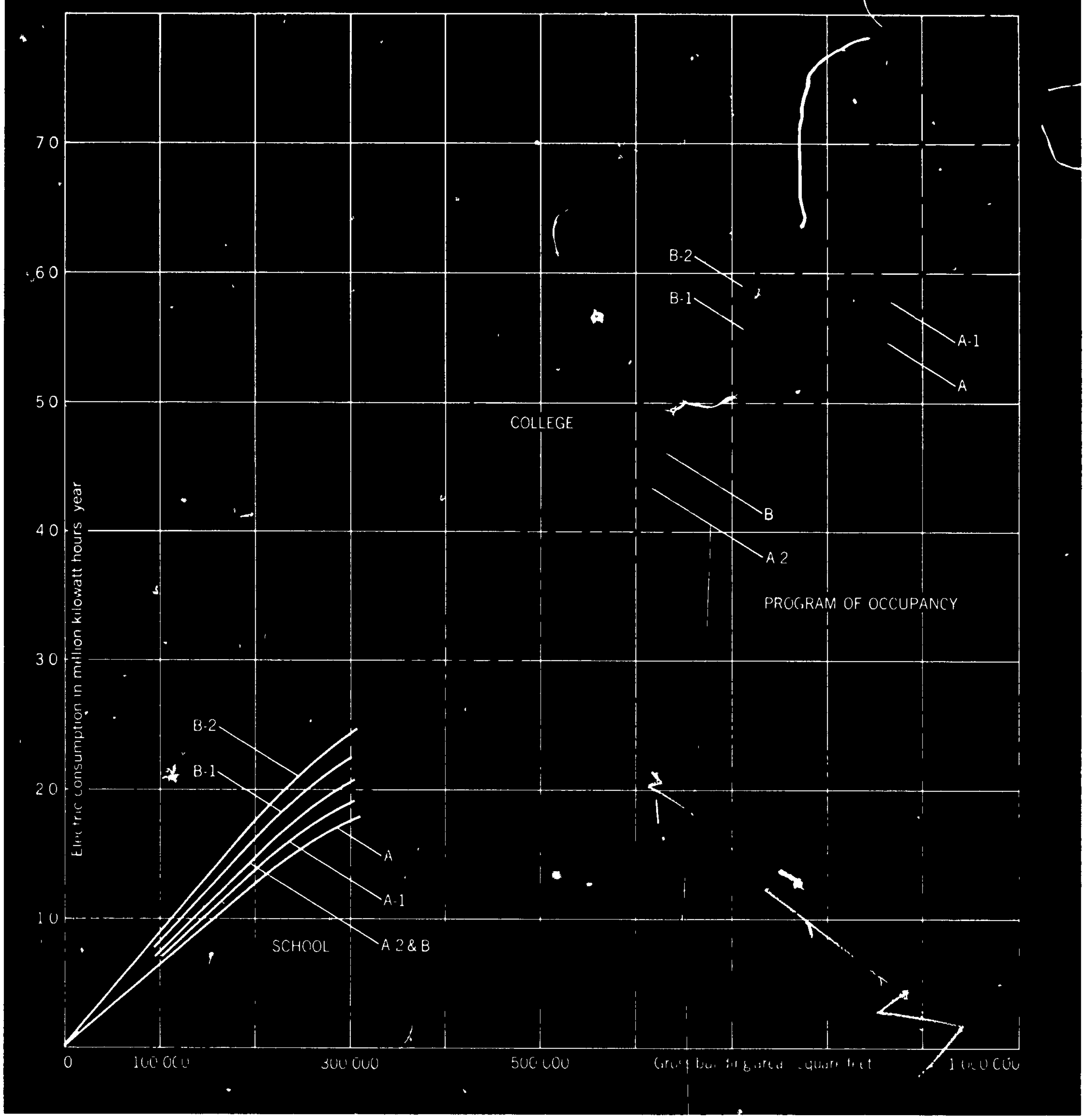


Figure 15. Annual electrical consumption for schools and colleges



Based upon the load profiles and using the same programs of occupancy as for the feasibility curves, the consumption per month and per year can be established in kilowatt hours. Figure 15 shows the annual power consumption as it varies with the gross square footage of a project. These power consumption figures and the load profiles are both based upon survey data and design experience. They are by necessity generalized to cover a variety of cases, but are a helpful guide in performing a study in the early stages of a project.

This information can be used to calculate total energy power generation capacity and to estimate the cost of electricity for a conventional system, especially when rates are figured on a graduated scale per month plus a demand charge per kilowatt hour for the highest recorded demand in a month.

service is not great, and therefore the minimum standby requirement would be equal to the largest module of the group of modules required to carry the maximum load.

The maximum load mentioned is actually an average maximum, which does not include transient surges of short duration in the demand. Usually generators are sized slightly larger than the maximum load. Even if the load slightly exceeds the capacity of the generators for a short period, this is not serious since the nominal capacity for most units can be exceeded from 5 per cent to 10 per cent for short periods. It would be more prudent to rely on standby capacity to handle unusual demands rather than to size the entire plant for them.

EQUIPMENT SELECTION CRITERIA

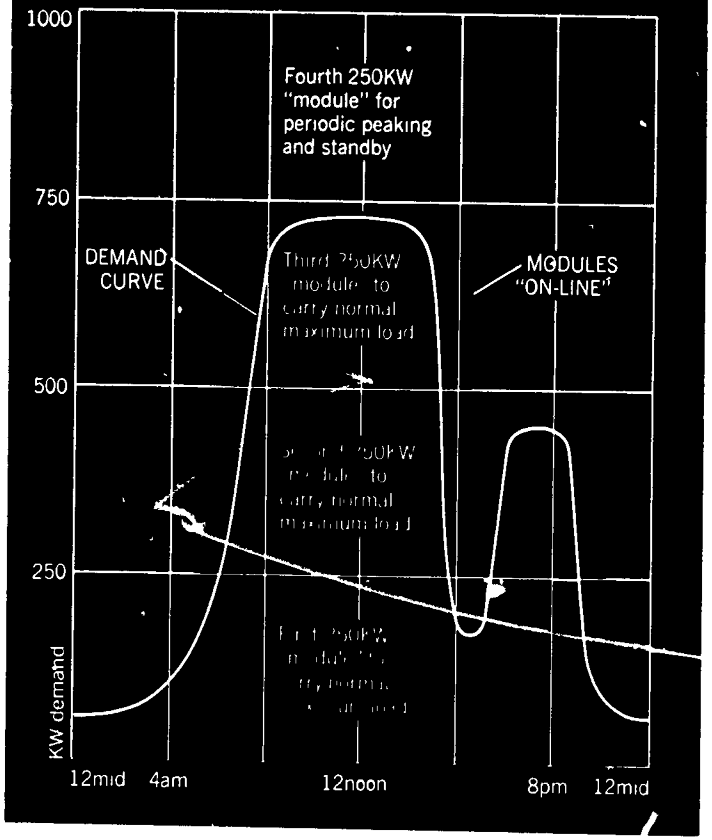
The total energy plant is made up of the prime mover-generator (reciprocating engine or turbine); controls; switchgear; heat-recovery equipment; supplementary boiler; absorption refrigeration equipment; an excess waste-heat exchanger for nonusable steam; and auxiliary pumps, sumps, and oil coolers. In the following paragraphs, the selection criteria for major components of a total energy plant will be examined.

Prime Mover

The heart of the system is the prime mover-generator, the size of which is determined by the load profile analysis. The question to be resolved in each selection is the type of prime mover, reciprocating engine or turbine, and the type of fuel to be specified.

The prime movers used in this report as a basis for preparation of the feasibility curves were reciprocating engines. The reason for this is that, at the present state of the art, the lower first cost and greater operating efficiency of the reciprocating engine yield a higher rate of return for the school and college application than the gas turbine. This is due principally to the fact that the reciprocating engine has reached a higher stage of engineering development than the turbine. Reciprocating engines have been in use for many years, whereas gas turbines in the smaller size category (less than 1000 kilowatts) for land-based power generation are a relatively recent development. The inherent characteristics of the turbine point to a bright future, however. It is much lighter and smaller than the reciprocating engine for the same horsepower or kilowatt rating, and it has a much lower potential maintenance cost. The wear and tear of the rotating motion of the turbine is basically less than that of the reciprocating engine. The smaller relative size and the simplicity of construction make it much easier to submit the turbine to an on-the-job overhaul.

Figure 16. Prime mover-generator sample modules



Since heat recovery for total energy is a primary concern, it should be noted that a gas turbine produces about twice as much recoverable heat as a reciprocating engine of the same size. Generally a turbine in this range can yield 7 to 13 pounds of steam per hour (15 psi steam) per kilowatt generated, whereas engines produce 4 to 6 pounds of steam (15 psi steam) per hour per kilowatt generated. An over-all system efficiency of slightly over 65 per cent is possible in turbine-powered total energy plants, if all the recoverable heat is used. Turbines, because of their higher heat output and lower shaft efficiency, are most applicable in situations in which a substantial amount of waste heat is required at all times that power is being generated. For schools and colleges where there are occasional periods of high electric demand with no simultaneous heating or cooling requirements, the turbine system's efficiency would be adversely affected much more than the engine's.

Another important point to consider when dealing with turbines or turbo-charged reciprocating engines (turbo-charged reciprocating engines can increase the capacity of a naturally aspirated engine considerably) is that they require fuel gas at higher pressures. Turbines require gas to be supplied at 100 to 150 psi. In many areas of the country, normal utility gas distribution is at less than 1 psi for the consumer. Such situations require the use of gas compressors which introduce an additional cost item as well as another link in the chain of reliability. If the compressor fails, so do the prime movers; hence a standby gas compressor is recommended. Compressors for the turbines in this size range can cost from $5,000 to $8,000 each. For the engines, a somewhat smaller and less expensive compressor is required.

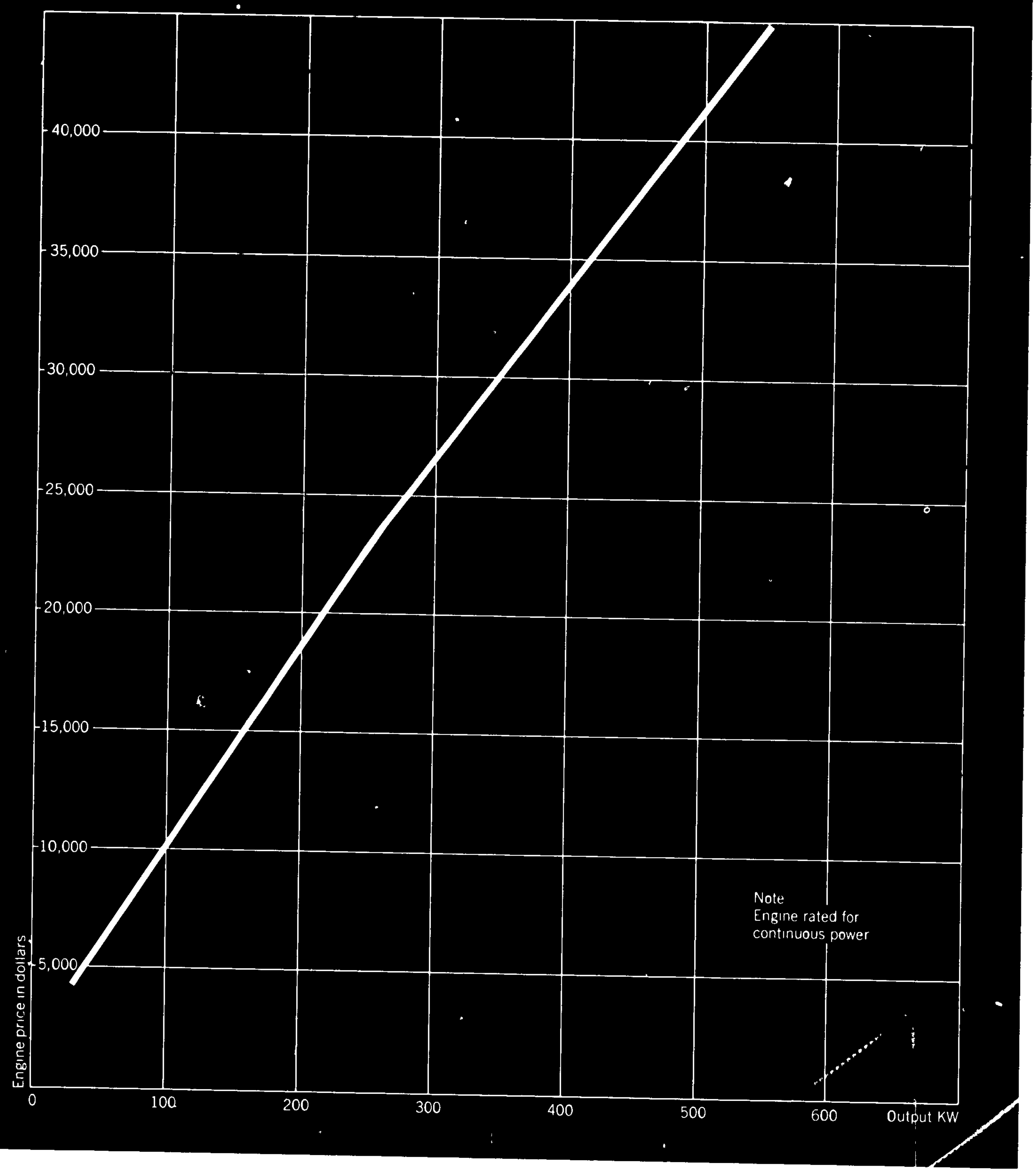
The selection of fuel for each application will be strictly a function of local conditions related to availability of fuels and the relative gas and fuel oil rates. Reciprocating engines can use either diesel or natural gas, and turbines can run on either natural gas or a high grade of fuel oil. Some areas of the country have lower "interruptable" gas rates than the "firm" rate. During certain periods when the "interruptable" gas is turned off (usually during extremely cold periods), standby can be provided using LP gas (propane). LP gas can be

Figure 17. Comparison of engine-turbine combinations

Zone II Program of occupancy A Electricity 2.5¢ KWH Gas $.50 MCF (Based on rate of return formula shown on pp. 20-21)

Building	300 000 SQUARE FT SCHOOL			500 000 SQUARE FT COLLEGE			1 000 000 SQUARE FT COLLEGE	
Engines	1 x 250 KW	3 x 250 KW	2 x 250 KW	3 x 450 KW 1 x 250 KW	3 x 450	2 x 350 KW	5 x 600 KW	4 x 600 KW
Turbines	–	1 x 250 KW	2 x 250 KW		1 x 250	1 x 250 KW 1 x 750 KW		1 x 750 KW
Net added cost for T E	$112 540	166 900	178 200	248 100	285 830	399 590	405 300	470 560
Conventional purchased power	$ 43 600	43 600	43 600	78 600	78 600	78 600	157 200	157 200
Gas Cost T E	$ 13 100	17 110	19 958	22 100	25 000	31 700	42 300	47 909
Maintenance T E	3 550	3 550	3 550	3 705	4 530	4 360	10 100	7 220
Depreciation & Interest T E	9 810	11 520	12 200	17 150	19 700	27 600	28 000	32 500
Recovered steam T E	3 125	7 060	8 500	6 830	12 200	14 650	13 650	18 900
Annual savings	$ 20 235	18 180	16 392	42 475	41 570	29 590	90 450	88 471
% return on investment in T E	11.2	10.9	9.2	17.1	14.6	7.4	22.5	18.8

Figure 18. Average price of reciprocating engine-generator set



The lower first cost of the reciprocating engine is attributed to the fact that the markets for them have been established for years, and total energy is merely one application for the engine which is mass produced. While turbines are no longer in the custom design stage, the standard models which are available still reflect higher engineering and production costs. Figures 18 and 19 show some of the current costs of engines and turbines in various categories.

stored in a tank buried on the site and supplied to the engine when required.

The reciprocating engines generally considered here are in the "high-speed" class of 1200-1800 R.P.M. Larger size, but slower speed, engines (900 R.P.M. or less) generally have longer life and higher efficiencies. These large engines also are available with the dual-fuel feature and can be operated on gas or diesel oil entirely or various combinations of both simultaneously. But these slow-speed engines are too large and often too costly for school or college applications where engine-generator modules of less than 1000 kilowatts are generally required.

The chart (Figure 17) compares reciprocating engines to turbines and to combinations of turbines and engines taking into account the factors of relative size, efficiency, and cost mentioned above. Using the measure of comparison advocated by this report, namely long-range return on investment dollars, the results indicate the best selection to be reciprocating engines in each case.

Controls and Switchgear

The subject of controls is quite broad, but fundamentally there are three categories for discussion purposes: fully automatic, manual, and semiautomatic. Fully automatic controls permit completely unattended operation in which the generators automatically sense the electric load on the system and bring the necessary generators on the line to handle the load. Such a system can automatically have the generators share the load equally or in a predetermined proportion. In a manual system, an operator turns on the necessary generators to meet the load and shuts them down as the load dictates. This is a simple procedure which only requires a few minutes. In order to operate and synchronize generators manually, a "swing panel" is required in addition to the other control modules. This panel contains the necessary instrumentation to indicate when the engine which is being started is synchronized (frequency and voltage) with those already in operation. At the right moment the operator can then throw the generator on the line. A semi-automatic system usually implies manual start and stop, with some automatic control features during the operation of the units, such as load sharing.

Figure 19. Typical gas turbine prices

Continuous output KW	Cost $
200	28,000
250	29,500
320	80,000
750	85,000
Note Cost includes basic unit only with manual controls	

Automatic controls are generally costly, but can pay for themselves in cases where they reduce the size of full-time operating staffs. This is likely in larger installations where the load fluctuations are not easily predictable, requiring constant attendance and surveillance. Automatic systems are complex and require careful maintenance if they are to perform properly for an extended period. For most schools and colleges, fully automatic controls are not necessary, since the load fluctuations are easily predictable, and a full-time operator in the total energy plant alone would not be necessary. In all likelihood, a centrally air-conditioned school would have a capable operator in the equipment room most of the time anyway, and the same person could easily operate the engine-generator sets. The operator could, after a few months of operation, easily determine the periods when he should attend to the generators to handle load changes. His other time would be free to operate and maintain other equipment. With a suitable set of alarms and automatic transfer switches, continued operation could be assured if the operator is in the vicinity.

Controls and switchgear generally can be obtained as a package, mounted in a cabinet with the necessary instrumentation (voltmeter, ammeter, voltage regulator. frequency indicator, etc.). Each prime mover-generator set would have its own control module, the complexity of which depends on the degree of automation desired.

The control system will generally be a form of compromise between the automatic and the manual, with the larger systems tending toward fully automatic and the smaller toward fully manual. The cost of automatic controls does not increase in proportion to the size of the installation, but is more nearly constant over a fairly wide range of sizes. Thus, on smaller systems the automatic controls would be a disproportionate percentage of the total cost. But on larger installations, greater savings can result from increased efficiency in exactly matching loads.

Heat Recovery

For *gas turbines* the waste heat available is in the form of exhaust gases. Heat is recovered from a turbine by means of a waste-heat boiler which resembles to a degree a conventional boiler in both appearance and operation. A duct similar to a breeching is connected directly from the exhaust of the turbine to the boiler. After passing through the boiler the gases are exhausted to the atmosphere. If the system is designed with an exhaust bypass around the boiler, a sound trap is required. Otherwise the boiler acts as a silencer.

The amount of heat which is recoverable is limited by the fact that it is impractical to reduce the temperature of the exhaust gases below 300 degrees F. At that temperature, condensation can start to form in the exhaust system, causing corrosive action. Also, the temperature of the steam or hot water being generated is approximately 250 degrees F., and as the temperature of the exhaust gas approaches this the heat transfer becomes less efficient. Attempts to recover more heat could cause undue back pressure on the turbine, decreasing its efficiency. The temperature of the exhaust gases increases with the load on the turbine and the inlet temperature; however, turbines generally have exhaust gas temperatures in the 700-to-1000-degrees F. range. Of the waste heat in the exhaust, 60 to 65 per cent is recoverable—approximately 50 per cent of the input energy to the turbine.

For a *reciprocating engine,* the thermal characteristics are somewhat different. Approximately one-third of the input energy goes into power generation, with the remainder dissipated in the form of heat equally divided among jacket cooling water and the exhaust gases. A small amount is dissipated in the oil cooler, in the intercooler (for turbocharged engines), and by radiation to the surrounding atmosphere. Approximately 95 per cent of the heat in the jacket water is recoverable and 60 to 65 per cent of the heat in the exhaust is recoverable, representing a total of about 45 per cent of the input energy to the engine.

Jacket water heat can be recovered by use of heat-exchangers or by bubbling the jacket water into steam directly at 15 psi and collecting it in a steam separator. This "ebullient" cooling system requires the engine to run at approximately 250 degrees F., which is slightly higher than conventional engines without this heat-recovery feature. The exhaust heat is recovered in the muffler, which serves as a heat-exchanger and silencer as well. The steam thus generated can also be collected in the same separator that collects the jacket water steam.

The amount of heat which can be recovered economically from the exhaust is subject to the same limitations of minimum temperature (300 degrees F.) as the exhaust from the turbine. Exhaust from the gas engine is often at 1100 degrees F. when fully loaded, whereas diesel exhaust runs lower, in the 800-to-900-degrees F. range. The mass flow through diesels is higher, however, and the total recoverable heat is only slightly less than the gas engine. The over-all system efficiency for diesels is quite comparable to the gas engine since less fuel input per kilowatt is required.

Sample Total Energy Plant: Design and Equipment Selection

Finally, to demonstrate the procedure of selecting components and developing cost estimates, examples of plant design are shown for schools and colleges of 100,000, 300,000, and 500,000 square feet. The load profile in Figure 13 was used as a basis for module sizing. Credits were taken for savings achieved in eliminating boilers, incoming electric service, and emergency lighting systems which would have been required for a conventional project. Controls were assumed to be a manual system with some interlocking features for automatic start-up of the standby in the event of failure of one engine.

DESIGNING THE PLANT

Space and Location

The ideal location for a total energy plant would be in the center of a building complex to minimize the length of utility distribution runs. Considerations of esthetics, noise control, use of prime property, and accessibility for service may preclude this central location, however. A balance of these factors against the minimization of utility runs will determine the ultimate location of the plant.

Generally, the same architectural and engineering principles which apply to the design and location of central heating and cooling plants apply to total energy plants, since much the same equipment is used. Typically, a total energy plant requires approximately 10 to 15 per cent more space than a conventional plant.

The central plant should house all the prime mover-generating equipment, electric switchgear, waste-heat recovery equipment, boilers, chillers,

Figure 20. Total energy cost estimates

pumps, and auxiliaries. The cooling tower should be nearby if possible, to keep the piping runs between the refrigeration equipment and the tower as short as possible. Air-intake louvers for the engines or turbines as well as exhaust openings will be required.

Sound and Vibration Isolation

Controlling sound and vibration transmission to neighboring areas is no more of a problem for a total energy plant than for a conventional heating and cooling plant. However, as with any boiler or refrigeration equipment, prudent judgment dictates that areas sensitive to noise should not be immediately adjacent to the total energy plant. Noise from the plant would be of two types, airborne and that which is transmitted through structural elements.

Airborne noise can be controlled to satisfactory levels by sound traps, mufflers, and acoustical enclosures. For turbines a sound trap is required on the air intake and generally in the exhaust if the plant is in an acoustically sensitive area. These traps are well-developed items, readily available commercially. Some turbine generator sets come completely packaged in acoustical enclosures which greatly reduce airborne noise in the equipment room itself. Engines require a muffler on the exhaust which can usually serve as a heat-exchanger for picking up heat from exhaust gases. The ambient noise level within the equipment room is generally high, and all openings to the outside should be carefully located and equipped with sound traps if necessary. The equipment room itself should be of heavy construction, including doors, to contain the noise within the room. If these design precautions are observed, airborne noise can be kept at an acceptable level.

Vibrations transmitted via the structure or piping can be handled by many of the same methods used in conventional heating and air-conditioning systems. Reciprocating engines should be mounted on a sturdy foundation which "floats" free of the basic structure. All attachments to the engines should have flexible connections. Turbines are inherently more vibration-free than engines. Their foundations can be lighter and more simply mounted. Separate footings are not necessary but flexible connections are recommended.

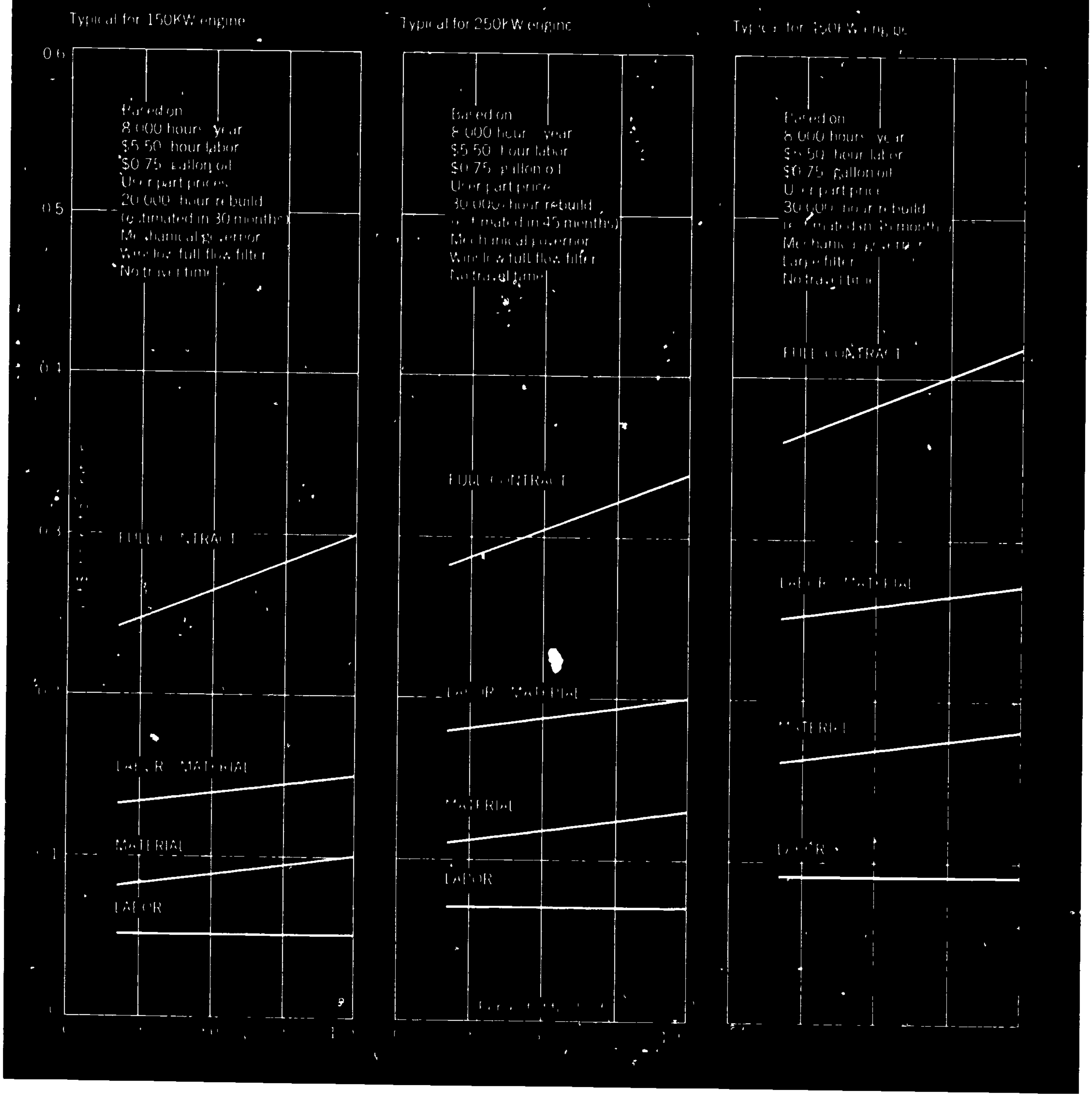
Dependability and Maintenance

During the course of this study many installations were visited and the operating personnel interviewed. The records of power outages were very few and not significantly different from that which could be expected from a normal utility. In most cases, where proper standby capacity was provided, limited service was always available during the short interval that the main plant was down. For properly designed plants with adequate maintenance, the reliability of the plant should be high. The equipment used is fundamentally long-life equipment with satisfactory histories of minimum-attendance operation.

As to maintenance, there are two basic approaches. One is to have a staff of trained mechanics who do all the maintenance of the power generating equipment, buying only the materials needed to keep the equipment in top condition. The other is to purchase a full maintenance contract from an outside service in which, on a periodic basis, trained servicemen go over all equipment, performing the necessary adjustments and overhauls. In such a contract, the service could also be on call for emergency situations. Combinations of these two, in which the on-site staff performs routine maintenance while the on-call service handles major problems and overhauls, are also possible.

The principal cost pertinent to a total energy feasibility study is that related to the engine-generator sets. Other equipment is comparable to that of a conventional heating and cooling plant and adds no extra cost.

Figure 21. Maintenance costs for reciprocating engines



Maintenance costs are given per operating hour for particular engine-generators. To determine the annual costs, one must calculate the number of hours each set will run in a year, and multiply this by the hourly cost. Some typical costs for engine generator sets are given in Figure 21. Maintenance costs for reciprocating engines have been fairly well established, as extensive operating histories have been tabulated. Costs on turbines are not well established; but they are generally a good deal lower than for engines. For turbines in the smaller class, 200 KW to 400 KW, hourly costs for estimating purposes are approximately $.30 per operating hour. This cost is quite conservative and reflects what an outside maintenance contract would cost. For larger turbines (above 500 KW) the cost does not increase as greatly as it does for engines, and would generally be 50% to 65% of a comparably sized engine.

5. Future Trends

Where will total energy go from here? Is the concept expected to sweep the country and slowly edge the giant electric utility companies out of business? Or—by the opposite token—could a school district's investment in total energy turn sour when a nuclear power plant begins offering electric energy at drastically reduced rates right in its own back yard? How confident can school boards and college administrators be that a valid decision to generate their own power in 1965 will be equally valid in 1980? In casting about for answers, these promises and problems appear on the total energy horizon.

Total Energy: A New Contender In The Ring

High electric power rates in a particular area are a major influence in attracting the economy-minded to total energy. Utility companies cannot be expected to remain unmindful of this sudden competition where little previously existed. Take what happened in Alberta, Canada, as an example. When West Jasper Place began planning its new air-conditioned junior high school (see p. 9), their designers suggested tapping the huge reserves of natural gas that lie deep beneath the central Canadian prairie and using it in generating electricity to meet the school's power demands. In remote West Jasper Place the average cost for purchased electric power would have run between 1.2 and 1.5 cents per KWH in 1962 (not an exorbitant amount), but engineering studies indicated that exceptionally low gas rates in the area made on-site power generation possible at a cost of only .71 cent per KWH *if* a total energy system were utilized. When the school board and the gas company began publicizing this fact, the electric power company responded by substantially reducing the electric power rates to other school districts which might be similarly persuaded. Instances of substantially lowered electric rates to meet total energy competition are reported in Florida and Texas as well. Indeed, this renewal of competition in an otherwise noncompetitive field may prove eventually to be total energy's single most important contribution.

Nuclear Power: Contender-in-Training

Another factor that will have to be reckoned with in the near future is the burgeoning atomic power industry. Pressures to reduce air pollution—New York's new mayor, John Lindsay, is only one of the persons working to eliminate coal-burning heat and power stations in his fair city—coupled with improved efficiency in atomic power generation have stimulated worldwide interest in this clean and flexibly locatable concept. The International Atomic Energy Agency expects that, by 1980, nuclear power may well account for 20 per cent of the world's electric energy needs.

But despite this enormous growth potential, the nation's largest atomic power equipment manufacturers do not see nuclear power as a threat to any of the more conventional sources of power. The growth of the atomic power industry is considered simply a measure of a continually increasing world demand for electric energy. Nuclear power is a new growth industry striving to meet this demand, but the total market is large enough to support a diversified field of power suppliers from oil and gas-fired to coal and hydro-powered generation.

Product Development, From The Ground Up

As with any new development (total energy in the strict sense isn't really new, but rather a new combination of several well-established principles), equipment selection for total energy plants has largely been limited to those items now economically available on the market. For this reason, gas and diesel engines have dominated the prime-mover field, owing to the design engineer's familiarity with their performance and efficiency. The large-scale development of products designed for total energy from the ground up is just begin-

The lights at Rochdale Village, a total energy project in Queens, continued burning througnout the November, 1965, blackout of the Atlantic Seaboard. Thereafter, the Federal Power Commission recommended that all essential institutions make provision for auxiliary emergency power. Electric generator suppliers soon came running. One, advertising in *The New York Times*, urged the harried public: "Don't get caught again with your plants down."

ning, however. Much of this development centers on gas turbines in the smaller size categories. The inherent simplicity, low maintenance, compactness, and long-life characteristics of gas turbines will no doubt lead to their further consideration for future on-site power generation plants.

High Frequency Lighting: An Added "Plum" Still Ripening

Conventionally, electric power is supplied at 60 cycles per second. However, on-site power generation, particularly with high-speed turbines, provides the option of generating power at frequencies other than 60 c.p.s. Since considerable operating efficiencies are inherent in high frequency lighting, it can be a significant design consideration. But, in spite of the theoretical advantages in high frequency lighting, there are still deterrents which have made its application in total energy schools and colleges less than practical.

While improved operating efficiencies are possible with high frequency lighting, there continue to be needs for conventional 60-cycle power for convenience outlets, appliances, clocks, and other electrical devices, requiring in effect that a dual-frequency system be provided. The resulting duplication in generation apparatus, switchgear, and distribution equipment increases first costs prohibitively. The advantages of high frequency lighting are most noticeable where fixture quantities can be reduced as in large expanses of luminous ceilings, but not all school areas are likely to present this opportunity.

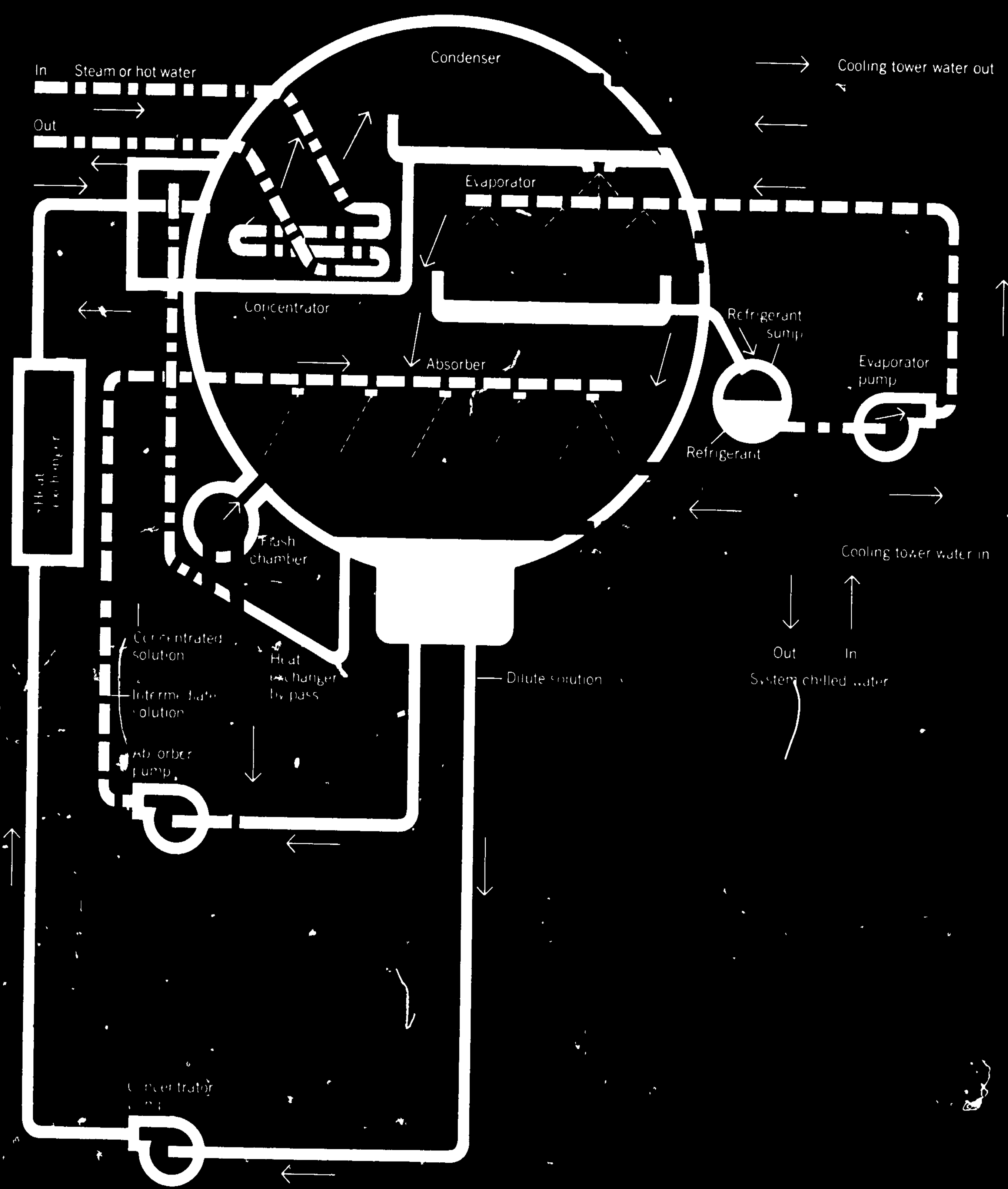
Education's Increasing Power Demands

The phenomenon of ever increasing demands for electric energy has not escaped the field of education. In the foreword to this report the various and sundry new demands that are being made of our educational system were enumerated. Ranging from expanded summer programs for preschool youngsters to late evening retraining programs for professionals, the burdens these new demands place on the actual physical facilities are invariably reflected in higher electricity requirements. If classroom lights are to continue burning and the school's power equipment and electronic teaching devices are to remain humming far into the night, the added burden in operating expenses is obvious. If students are to learn as effectively in hot August as in cool October, the need for all-weather climate conditioning within the classroom is equally obvious

And so we return to our original thesis: that new demands and new urgencies are placing increasing burdens on the schoolhouse and the college physical plant, and that administrators, architects, and engineers are facing the responsibility of seeking new ways to minimize the inevitable added expense in mechanical equipment and increased fuel and energy consumption. Where conditions are right, the total energy concept emerges as a feasible and economic long-range approach to satisfying these mounting equipment and energy requirements.

To define these conditions of feasibility has been the purpose of this report.

Figure 22. Schematic of the absorption cycle



Appendices

A. Absorption Refrigeration

One of the factors which stimulated interest in total energy is the development of the absorption refrigeration unit which uses steam as the energy source to create a cooling effect. By using an absorbent chemical and controlling its characteristics between the supplied steam and the cooling tower water, chilled water is generated to handle the building cooling load. The steam requirements vary with the cooling load. A schematic diagram of the process is shown in Figure 22.

This type of unit provides a means of using the waste heat whenever mechanical cooling is required, which makes the total energy system practical. Use of absorption is by no means restricted to total energy, and, in many areas where fuel oil or gas is reasonably priced and the cost of electricity is high, it is used because of low operating cost. In fact, very often the same set of circumstances under which total energy would be feasible, namely lower fuel oil or gas rates and higher electric rates, would be conducive to employing absorption air conditioning. In other words, if total energy were economically justified, absorption cooling would have approximately the same owning and operating cost as electric-driven units and possibly would have even lower costs if conditions strongly favor total energy.

In preparing the feasibility curves, the most economical conventional system was used as a basis for comparison. Since in the range of feasibility of total energy, absorption cooling is equivalent to, or is, the most economical conventional cooling system, it was assumed for the conventional school.

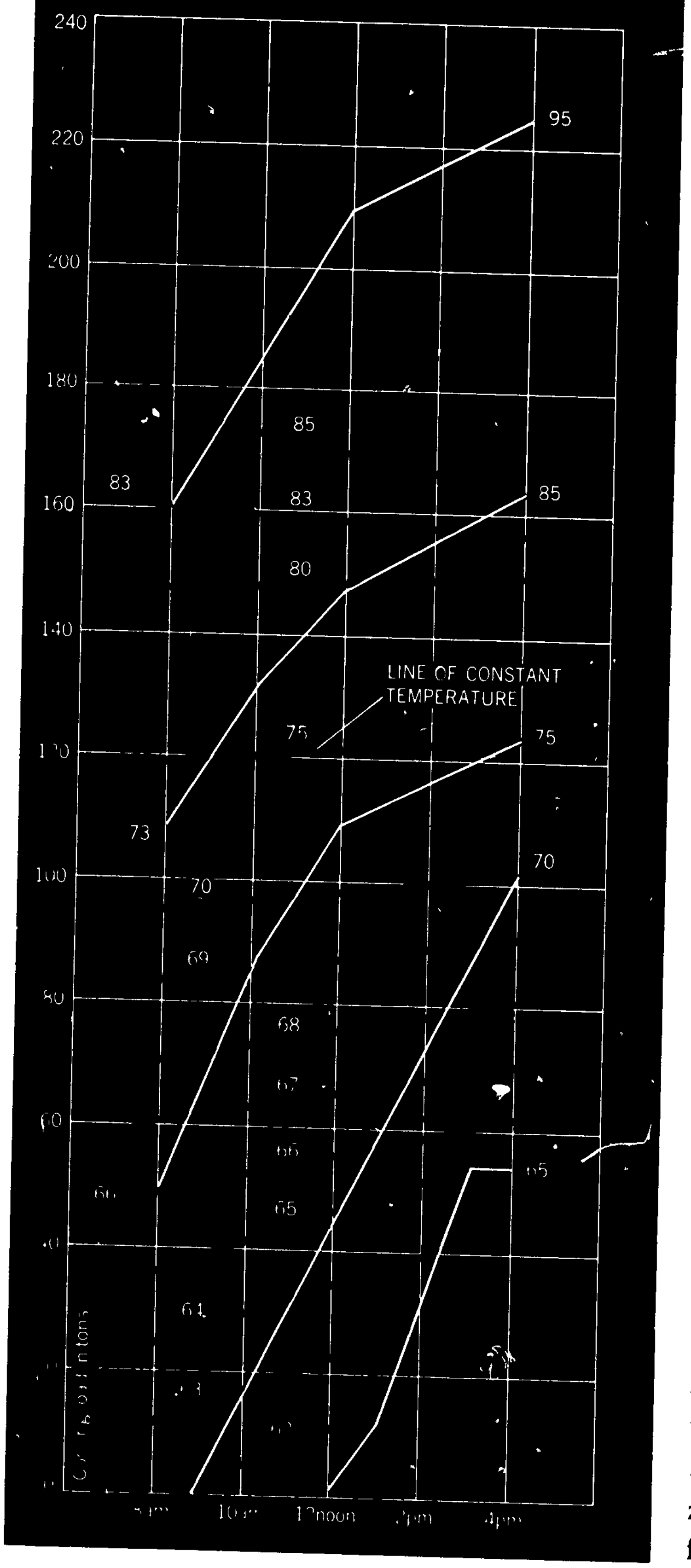
B. Heat-Recovery Analysis

The determination of how much heat will be recovered from the total energy plant can be complex. For any given project, it involves the program of occupancy and the variation of the electrical, heating, and cooling loads, with the latter two being functions of the weather. No two months or years are ever exactly alike; however, there are patterns which tend to hold true over a period of years.

The objective of the heat-recovery calculation is to determine how often during the year the heat given off from the engines can be put to use. It is not necessary to know how the heating or cooling load varies throughout the entire year, but merely when there is enough demand to use the steam generated by the engines for heating and cooling. The fuel consumed by the supplementary boiler is not significant, since we are comparing the total energy system with a conventional system which would have to meet those same demands with a boiler also. What is different is that the conventional system must meet the entire demand by consuming fuel in the boiler, whereas in total energy we are obtaining a certain portion of this energy supply as a "free" by-product of power generation. Hence in the feasibility calculation, we are seeking how much of a credit we receive on our operating cost by the recovered heat as a legitimate fuel saving compared to the conventional schoolhouse.

The first step is to determine under what climatic conditions the waste heat from the generators is required. This means that, under various conditions of occupancy which determine the power demand and in turn the waste-heat availability, there is an outdoor temperature condition below which all the waste heat available is needed for heating, and another outdoor temperature condition above which all the steam produced by the waste heat is needed for cooling. The deter-

Figure 23. Cooling load variation with outside temperature—100,000 square foot school



mination of these temperatures is a function, to a degree, of the construction of the building, e.g. walls, glass area, roof, amounts of insulation, etc. A significant factor, however, is the high internal load of lights and people. The temperature below which the available waste heat can be utilized during the normal daytime occupied cycle or during the full evening program is 40 degrees F. During all other periods, when the amounts of waste heat available and internal heat accumulations go down substantially, this temperature becomes 50 degrees F. For cooling, the picture is slightly different. During the in-between seasons, the air-distribution system can be run on 100 per cent outside air, which is effective in cooling the space when the outside air temperature is below 65 degrees F.

Using a 100,000-square-foot school as an example, the variation of cooling load with outside temperature is shown in Figure 23. A valuable way of graphically representing the load profile relations between electrical power, heating, cooling, and waste-heat availability at various outdoor temperatures is to superimpose them. An example of this is shown for a typical 100,000-square-foot school in Figure 24.

The next step is an analysis of weather data for the region to determine how many hours in a year during the different periods of occupancy the ambient temperature is above or below the determinant temperature. This can be a tedious process, but data is available from the weather bureau which enables one to sum up fairly quickly the hours in each month during different periods of the day during which the ambient temperature falls into these categories. In Figure 25 are typical summaries of weather data for a city in Zone II. Figure 26 is a summary of the information needed to calculate the waste-heat recovery for a typical 500,000-square-foot college for the three different zones, selecting Bismarck, North Dakota; Hartford, Connecticut; and Atlanta, Georgia, as

Figure 24. Total heating, cooling, and electrical load profiles—100,000 square foot school

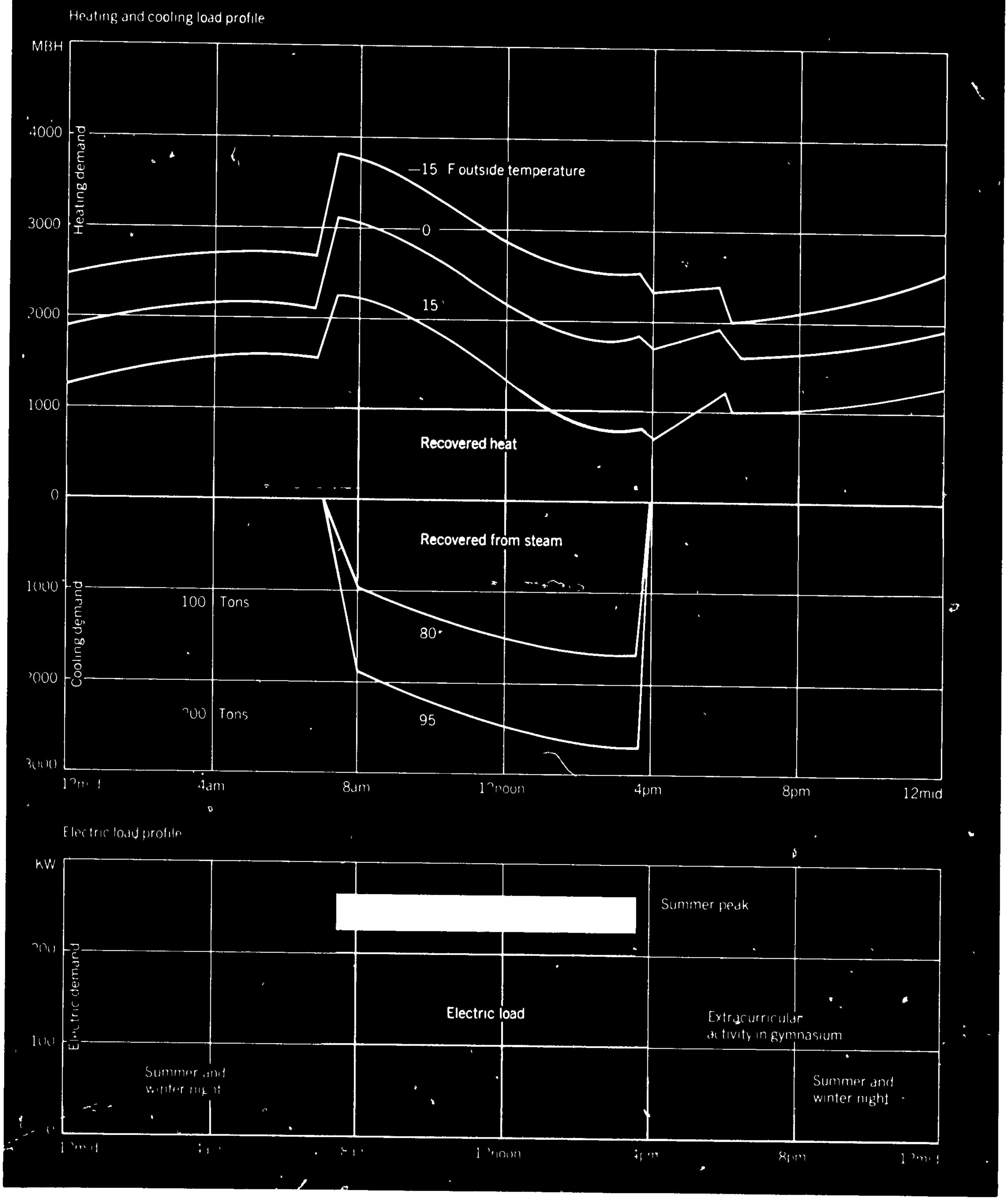


Figure 25. Summaries of weather data for a city in zone II

City Hartford Year 1963	TOTAL HOURS OF OCCURRENCE Day 8 00 am—4 00 pm													
Outside temperature F	J hours	F hours	M hours	A hours	M hours	J hours	J hours	A hours	S hours	O hours	N hours	D hours	Total hours	%
Below— -11														
-10— 0	1	6										1	8	0 27
1— 9	21	23										18	62	2 20
10— 19	47	53	1									73	175	6 00
20— 29	79	74	24								3	85	268	9 16
30— 39	90	60	141	6	2					2	31	64	407	13 93
40— 49	10	7	43	75	15				8	32	101	6	287	9 83
50— 59			27	100	70	33	3	5	75	78	93		477	16 35
60— 69			4	43	88	54	40	64	77	61	9		443	15 15
70— 79			4	16	61	86	108	133	65	57	3		530	18 15
80— 89					12	55	63	45	12	18			205	7 02
90— 99						11	33						44	1 51
100— 109														

City Hartford Year 1963	TOTAL HOURS OF OCCURRENCE Evening 6 00 pm—11 00 pm													
Below— -11														
-10— 0												2	2	
1— 9	13	20										9	42	
10— 19	38	35										51	124	
20— 29	55	47	11								6	56	175	
30— 39	47	36	111	20					1	9	25	37	286	
40— 49	2	2	32	66	22	1			14	28	64		231	
50— 59			1	57	66	24	3	16	69	62	46		344	
60— 69				7	50	46	50	69	45	49	9		325	
70— 79					13	64	66	66	23	7			239	
80— 89					4	16	35	4					59	
90 99							1						1	
100 109														

City Hartford Year 1963	TOTAL HOURS OF OCCURRENCE Night 4 00 pm 8 00 am													
Below -11														
-10 0	5	12										11	28	
1 9	60	87										68	215	
10 19	121	97	8									158	384	
20 29	181	151	125	12					1		24	175	669	
30 39	119	93	262	148	34				31	67	117	76	941	
40 49	10	8	65	194	142	15	9	17	95	156	201	5	917	
50 59			31	85	194	161	61	111	185	167	133	3	1144	
60 69			4	33	85	182	203	256	119	69	5		947	
70 79			1	8	33	86	160	93	44	35			456	
80- 89					8	31	51	19	5	2			116	
90 99						5	12						17	
100 109														

Figure 26. Heat recovery summary—typical 500,000 square foot college

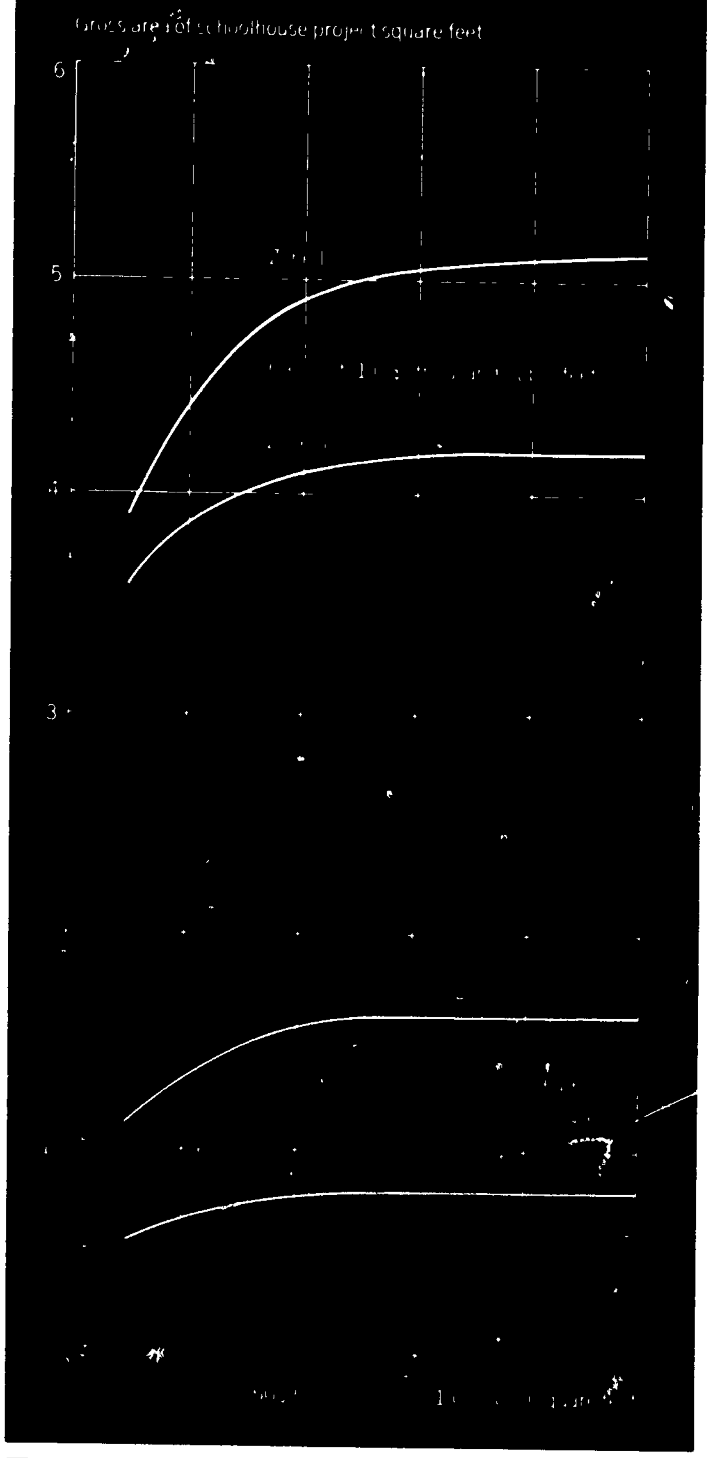
Item	Months	Time	KW	Lbs hour	T	Bismarck hours	Hartford hours	Atlanta hours
1 Cooling week day	9					287	272	603
	12	8 am 4 pm	1125	6560	tc 65	684	688	1065
2 Heating week day	9 & 12	8 am-4 pm	900	5250	th 40	693	604	233
3 Cooling extracurricular	9					72	68	152
	12	4 pm 6 pm	720	4275	tc 65	138	139	215
4 Heating extracurricular	9 & 12	4 pm 6 pm	600	3500	th 50	306	203	158
5 Heating dormitory	9 & 12	6 pm 11 pm	350	2000	th 50	636	615	391
6 Heating night	9 & 12	11 pm 8 am	150	1050	th 50	1395	1460	820
7 Heating Saturday gym	9 & 12	4 pm 6 pm	400	2600	th 50	77	65	39
8 Heating 1 night week auditorium	9 & 12	6 11 pm	320	1100	th 50	108	102	78
9 Cooling 1 night week auditorium	9					38	26	108
	12	6 pm 11 pm	440	2700	tc 65	38	[illegible]	105
10 Heating dormitory week end		8 am 11 pm	220	1350	th 50	578	509	178
11 Heating night week end		11 pm 8 am	150	1050	th 50	557	[illegible]	[illegible]
12 Heating vacation	9				th 50	[illegible]	[illegible]	
	12	11 pm 8 am	150	1050				
13 Heating vacation		4 pm 11 pm	150	1350	th 50	[illegible]	[illegible]	[illegible]
14 Heating vacation		8 am 4 pm	150	1350	th 50	[illegible]	[illegible]	[illegible]
15 Correction on heating vacation		8 am 4 pm	900 220	3900	30 th 50	[illegible]	[illegible]	[illegible]
16 Cooling 2 evenings week	9					[illegible]		30
	12	6 pm 11 pm	1040	6070	tc 65	[illegible]	[illegible]	[illegible]
17 Cooling 4 evenings week	9				tc 65	[illegible]		
	12	6 pm 11 pm	1040	6070	tc 65	[illegible]	1	[illegible]
18 Heating 2 evenings week	9 & 12	6 pm 11 pm	840	4900	th 50	[illegible]	[illegible]	[illegible]
19 Heating 4 evenings week	9 & 12	6 pm 11 pm	840	4900	th 50	[illegible]	194	[illegible]

specific areas.

The domestic hot-water heating loads have not been included in this analysis because of the variety of means at the disposal of the engineer to shift this load to different times of the day by using storage. The demand imposed on the heating plant by the domestic hot water is transient and usually of short duration. With little storage capacity, this would impose a large daytime demand on the system, which usually would require firing the supplementary boiler, in which case the total energy plant would be handling the demand much as a conventional school. With greater storage, the domestic hot water can be heated at night; however, the waste heat available at night is quite small since the engines are not heavily loaded. Thus, the supplementary boiler is also required in this case, which is again similar to the conventional school. It is conceivable that at times the waste heat from the engines can be used to heat the domestic hot water, but the periods would be short and the quantities small. Since the approach of the report has been a conservative one, it was decided that, in order to be considered feasible, total energy should justify itself without credit for the indeterminant variable of domestic hot water.

In preparation of the feasibility curves, heating and cooling loads were developed assuming a fairly well-insulated building. Consideration was given to variations in the thermal characteristics, especially different wall and roof construction. Calculations were made to determine the effect of changing the heat transmission coefficients ("U" factor) of the wall and roof on the heat recovered and on the rate of return on the total energy investment. In the curves in Figure 27 the effect on the rate of return is shown for doubling the wall U factors and increasing the roof U factor by 50 per cent. The reason the rate of return increases is that, as the U factors increase, the heating or cooling load at any time increases. This means the waste heat can be used at a higher temperature than before for heating and conversely for cooling. Thus the credit for heat recovery is greater, giving a slightly greater rate of return. The effect is so slight, however, that it is practically negligible.

Figure 27. Effect of increasing heat transmission coefficients of buildings



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